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THE UNIVERSITY OF ALBERTA

A REGRESSION MODEL FOR IRRIGATION WATER USE
ANALYSIS IN THE EASTERN
IRRIGATION DISTRICT

by

© Ghulam Nabi Chaudhary

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

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AND RURAL SOCIOLOGY

EDMONTON, ALBERTA
SPRING, 1975

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "A Regression Model for Irrigation Water Use Analysis in the Eastern Irrigation District" submitted by Ghulam Nabi Chaudhary in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

This study emphasized the identification of factors which influence irrigation water use in the South Saskatchewan River Basin of Alberta. On the basis of these factors, a regression model was developed for irrigation water use analysis in the area under study. Initially, the decision was to include the entire area but data availability was a problem. Hence, efforts were concentrated in the Eastern Irrigation District, for which the data were readily available. The variables in the model were water use (gross diversions) in acre-inches as the dependent variable, and consumptive use requirements, acreage irrigated for different crops, average weather conditions and precipitation during the pre-growing season as the independent variables.

The consumptive use requirements for each crop were calculated by using the Blaney-Criddle Formula, which takes into account temperature, daytime hours during the season and precipitation. The calculated consumptive use figures were multiplied by the acreage of the respective crop in order to arrive at the water requirement for that particular crop. Then the crops were divided into different groups on the basis of management pattern and water requirements and the total irrigation water requirements for each group of crops were arrived at by simple addition.

The independent variables explained 84 percent of variation in water use. The statistical tests showed significant relationship between the variables. The model developed for irrigation water use analysis for the Eastern Irrigation District, could be applied to other irrigation districts in the South Saskatchewan River Basin Area, if data are made available.

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TABLE OF CONTENTS

CHAPTER		Page
I	INTRODUCTION	1
Definition of the Problem	1
Objectives of the Study	5
Scope of the study	5
Data Collection	7
II	THEORETICAL FRAMEWORK OF WATER DEMAND	9
Basic Concepts and Definitions	9
Production Function with Two Variable Inputs	12
Derived Demand for Water	16
The Market Demand Curve	20
Water Demand for the Eastern Irrigation District	22
III	IRRIGATED AGRICULTURE IN THE EASTERN IRRIGATION DISTRICT	25
Agricultural Production in the Eastern Irrigation District	27
IV	METHOD OF ANALYSES	31
Model Development	33
Evapotranspiration	36
Precipitation	41
Crop Grouping	43
Economic Factors for Changes in Acreage	43
V	THE ANALYTIC RESULTS	46
Empirical Regression Model	47

CHAPTER Page

VI SUMMARY 54

Summary 54

Implications of the Study 55

Limitations of the Study 56

Further Research Needs 57

SELECTED REFERENCES 59

APPENDIX 64

LIST OF TABLES

Table Page

3.1 Range and Average for Water Diverted and Acreage Irrigated for Various Crops in the Eastern Irrigation District 30

4.1 Total and Effective Monthly Precipitation . . . 42

5.1 Regression Model Results 51

APPENDIX

Table

1 Seasonal Consumptive Use Coefficient (K) for Crops in the Eastern Irrigation District 68

2 Average Monthly Temperature (T), Average Rainfall (r) and Effective Rainfall (re) in the Eastern Irrigation District from 1958 to 1972 69

3 Computed Normal Monthly Consumptive Use and Irrigation Requirements for ALFALFA in the Eastern Irrigation District 70

4 Computed Normal Monthly Consumptive Use and Irrigation Requirements for PASTURE in the Eastern Irrigation District 71

5 Computed Normal Monthly Consumptive Use and Irrigation Requirements for GRASS in the Eastern Irrigation District 72

6 Computed Normal Monthly Consumptive Use and Irrigation Requirements for CLOVER HAY and SEED in the Eastern Irrigation District 73

7 Computed Normal Monthly Consumptive Use and Irrigation Requirements for POTATOES in the Eastern Irrigation District 74

8 Computed Normal Monthly Consumptive Use and Irrigation Requirements for CORN in the Eastern Irrigation District 75

Table Page

9 Computed Normal Monthly Consumptive Use and Irrigation Requirements for WHEAT in the Eastern Irrigation District 76

10 Computed Normal Monthly Consumptive Use and Irrigation Requirements for FLAX in the Eastern Irrigation District 77

11 Computed Normal Monthly Consumptive Use and Irrigation Requirements for BARLEY in the Eastern Irrigation District 78

12 Computed Normal Monthly Consumptive Use and Irrigation Requirements for PEAS in the Eastern Irrigation District 79

13 Precipitation during the Pre-growing Season . . 80

14 Area Irrigated (in acres) and Net Consumptive Requirements (in inches) for Different Crops in the Eastern Irrigation District 81

LIST OF FIGURES

Figure		Page
1.1	Map Showing the Eastern Irrigation District in the South Saskatchewan River Basin Area	4
1.2	Consumption of Irrigation Water at Different Stages	7
2.1	Total, Average and Marginal Products and Stages of Production	11
2.2	Isoquants Showing Different Combinations of Inputs	13
2.3	Production Function with Two Input Variables	14
2.4	Demand Curve of the Producer	19
2.5	The Market Demand Curve	22

CHAPTER I

INTRODUCTION

DEFINITION OF THE PROBLEM

The planning, design and implementation of water resources development programmes entail many kinds of decision making. Planning decisions are made by the community, the electorate, legislative bodies and administrative agencies. Each level plays its own role in resource development and each is best adapted to specific types of decisions.

The major objective of water resources planning is to make effective use of available water resources to meet foreseeable short- and long-term regional needs. In a growing economy the demand for goods, services and necessities such as food can generally be expected to increase as population and incomes rise. In view of expected population increases, many of today's planners and policy makers feel it will be necessary to increase the amount of irrigated agriculture, a condition which may require considerably more water for irrigation than is presently used.[1]

Water is one of the major input factors affecting agricultural output in the South Saskatchewan River Basin

---

[1] Herbert W. Grubb, "Competition for Water in an Expanding Economy: The Case for Irrigated Agriculture," Water Resources and Economic Development of the West, Report No. 16 (San Francisco: Western Agricultural Economic Research Council, 1967), p. 215.

(SSRB) of Alberta. The Irrigated area of the SSRB relies heavily on agriculture as its economic base, and a large portion of agricultural production enters the national and international markets. Wheat, feedgrain and livestock production are the important activities in this area. In 1969, the estimated values of these agricultural products for the area were $99.9 million, $70.0 million and $151.5 million, respectively. Commercial vegetable production, excluding potatoes, was valued at $1.06 million in the same year, constituting 99.8 percent of the value of vegetable production in Alberta.[2]

The SSRB irrigated area has the potential to increase agricultural production if the presently available water is used economically and efficiently or if more water is made available for agricultural activities in the area. Although dry farming is possible in this area, water is considered one of the important inputs when production per acre is taken into account. Specialists in the area indicate that corn, alfalfa, sugar beets, potatoes, wheat, barley and all other crops respond well if an optimum level of water is applied to these crops.[3] On the other hand, it has been observed that often the cropped fields are irrigated irrespective of the reguirment of a crop. This practice causes wastage of water and sometimes results in negative effects on the productivity of the soil.

---

[2] Statistics obtained from Alberta Agriculture, Edmonton, Alberta.

[3] Personal interviews with crop specialists in the Department of Agriculture, Regional Office, Lethbridge, Alberta, 1973.

With improvements in technology and ample fertilizer supplies, water use in the SSRB is continuously increasing. In the case of the Eastern Irrigation District (EID), water use has increased from 478,700 acre-feet in 1958 to 556,840 acre-feet in 1972. Similar increases have been observed in other irrigation districts in Southern Alberta. More than 85 percent of the total water used is devoted to agriculture.[4]

This study focused on the development of a regression model to analyse irrigation water use[5] in the EID. Activities constituting water use were identified and related data were collected to test the model formulated. This study dealt with only one of the irrigation districts (i.e., EID) in the SSRB area of Alberta. Analysis were not extended to other irrigation districts primarily because of inadequate data.

The area comprising the Eastern Irrigation District is bound on the north by the Red Deer River and on the south by the Bow River (Figure 1-1). This district is located in South Central Alberta, between Calgary and Medicine Hat on the Trans-Canada Highway and the main line of the Canadian Pacific Railway. (More details on the district are presented

---

[4] Roger B. Long, "An Income Maximization Model for the South Saskatchewan River Basin of Alberta" (unpublished report, Phase III, Department of Agricultural Economics & Rural Sociology, University of Alberta, Edmonton, 1973), p. 9.

[5] Water use is the quantity of water demanded at a specific time for irrigation. Water use represents gross water diversion in the EID.

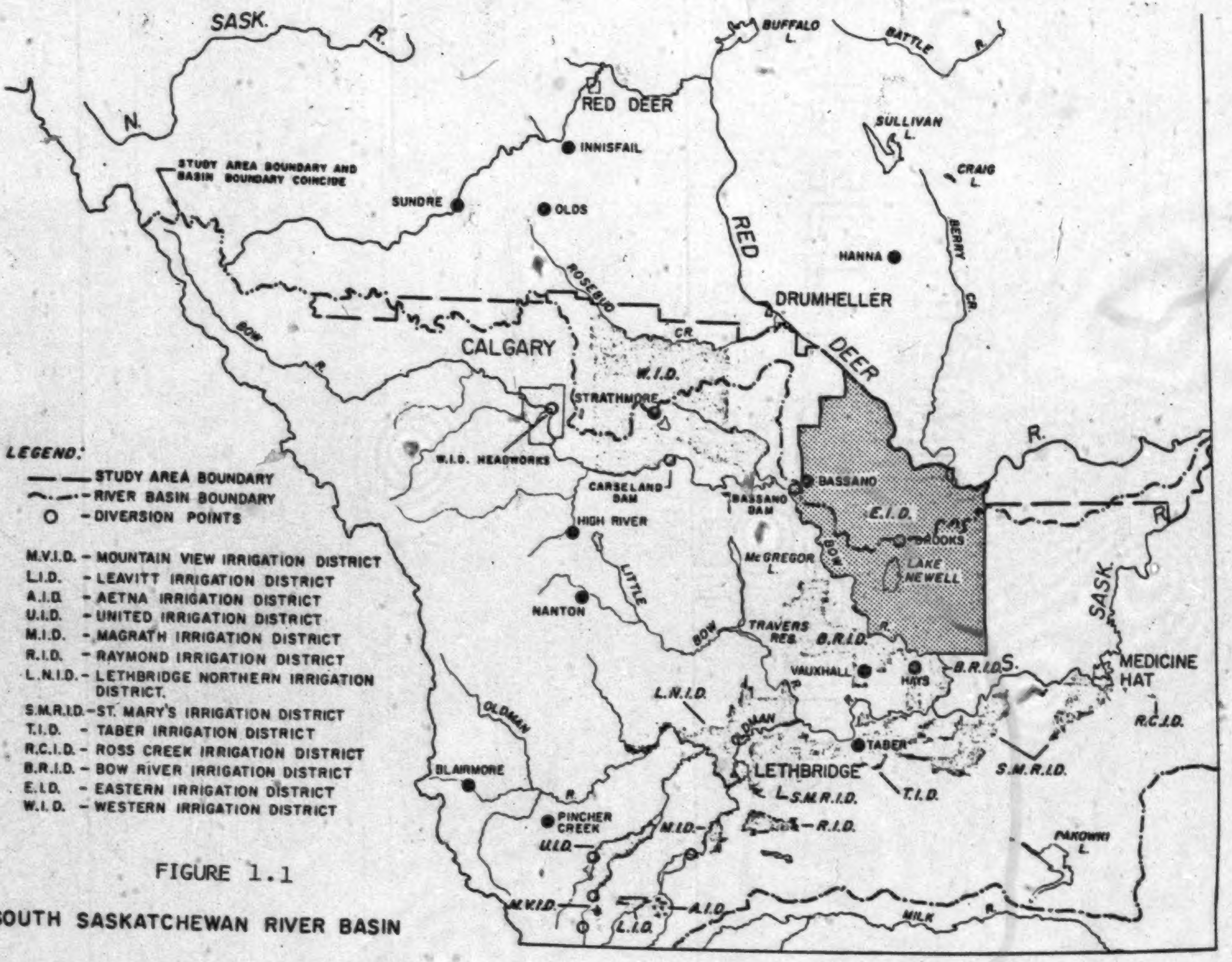

SASK.
R.
N.
RED DEER
INNISFAIL
SUNDRE
OLDS
STUDY AREA BOUNDARY AND BASIN BOUNDARY COINCIDE
BUFFALO L.
BATTLE R.
SULLIVAN L.
CRAIG L.
RED
HANNA
BERRY CR.
DRUMHELLER
DEER
R.
ROSEBUD
CR.
CALGARY
BOW
R.
W.I.D.
STRATHMORE
W.I.D. HEADWORKS
CARSELAND DAM
BASSANO DAM
BASSANO
E.I.D.
BROOKS
LAKE NEWELL
BOW
R.
HIGH RIVER
McGREGOR L.
LITTLE
NANTON
BOW
TRAVERS RES.
B.R.I.D.
VAUXHALL
HAYS
B.R.I.D.
S.
SASK.
R.
MEDICINE HAT
R.C.I.D.
L.N.I.D.
OLDMAN
OLDMAN
TABER
LETHBRIDGE
S.M.R.I.D.
T.I.D.
S.M.R.I.D.
R.I.D.
BLAIRMORE
R.
PINCHER CREEK
U.I.D.
M.I.D.
PAKOWKI L.
M.V.I.D.
L.I.D.
A.I.D.
MILK
R.
LEGEND:
STUDY AREA BOUNDARY
RIVER BASIN BOUNDARY
○ - DIVERSION POINTS
M.V.I.D. - MOUNTAIN VIEW IRRIGATION DISTRICT
L.I.D. - LEAVITT IRRIGATION DISTRICT
A.I.D. - AETNA IRRIGATION DISTRICT
U.I.D. - UNITED IRRIGATION DISTRICT
M.I.D. - MAGRATH IRRIGATION DISTRICT
R.I.D. - RAYMOND IRRIGATION DISTRICT
L.N.I.D. - LETHBRIDGE NORTHERN IRRIGATION DISTRICT.
S.M.R.I.D. - ST. MARY'S IRRIGATION DISTRICT
T.I.D. - TABER IRRIGATION DISTRICT
R.C.I.D. - ROSS CREEK IRRIGATION DISTRICT
B.R.I.D. - BOW RIVER IRRIGATION DISTRICT
E.I.D. - EASTERN IRRIGATION DISTRICT
W.I.D. - WESTERN IRRIGATION DISTRICT

FIGURE 1.1

SOUTH SASKATCHEWAN RIVER BASIN

in Chapter III.)

OBJECTIVES OF THE STUDY

The objectives of this study are:

1. To identify and evaluate the effect of various factors affecting irrigation water consumption in the irrigation area of the Eastern Irrigation District and to estimate the parameters associated with these factors.
2. To develop and test a regression model to be used for analysing irrigation water use in the EID.

SCOPE OF THE STUDY

Although there are different uses for water (for example, industrial, domestic and recreational), this study is only concerned with the development of a regression model to analyse irrigation water use in the EID. The reasons for emphasizing irrigation are that it is the major source of potential increase in water use and is the major basis for possible future investments in water resources. In general, apart from natural physcial factors, water used for irrigation depends on product prices, technology and complementary input cost to farmers. However, information on some of these variables was not readily available; hence, they were not incorporated in the model. Other variables identified for inclusion in the regression model were: consumptive use requirements, acreage under irrigation, average weather conditions and precipitation during the pre-growing season (i.e., January to April).

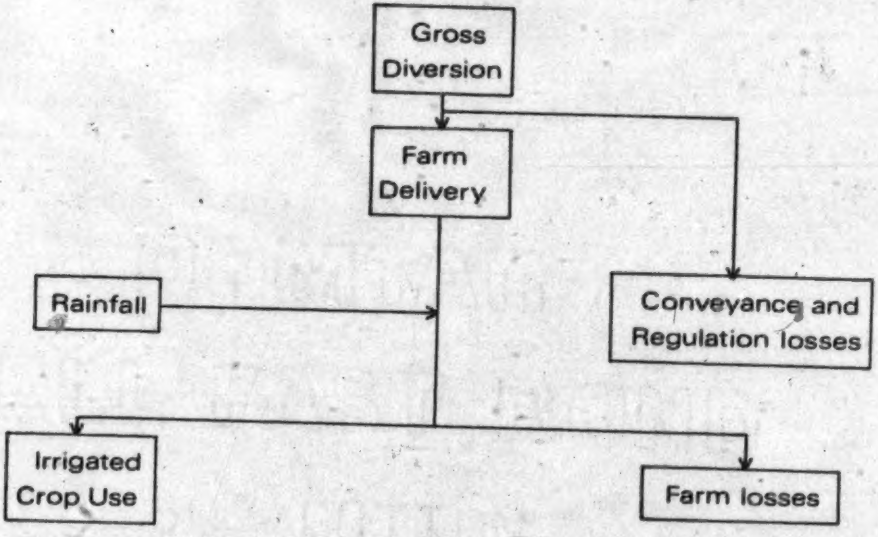
Gross water diversions in the EID have been measured in acre-inches and are presented in schematic form to indicate distribution at different levels.

When water is diverted from the main canal to farm fields, some water is lost enroute. These losses are called conveyance and regulation losses. The water which is lost on the farm is called the farm loss. Both types of losses occur through seepage, leakage and evaporation. Figure 1.2 depicts the flow of water and the water losses at various stages and also takes rainfall into account. However, the items of supply in a hydrologic budget theoretically should equal the items of disposal. Therefore, in applying such a budget, the gross diversion per irrigation acre plus the total rainfall during the irrigation season (May to October, in general, but different for different crops) should be balanced by the water used by crops plus total irrigation losses.

Information on water losses through seepage of water in ditches and other water losses are usually lacking in the area under study. However, the water losses in this study were accounted for by using data on gross water diversions. It is assumed that the water losses in delivery to farm fields are proportional to the water used in irrigating crops.

Figure 1.2

Consumption of Irrigation Water at Different Stages


Gross Diversion
Farm Delivery
Rainfall
Conveyance and Regulation losses
Irrigated Crop Use
Farm losses

Source: E. Rapp, et al., "A Hydrological Budget for a Southern Alberta Irrigation District," Canadian Agricultural Engineering, Vol. II, No. 2 (November 1969), pp. 54-57.

DATA COLLECTION

The secondary data for this time-series study covered a period of fifteen years (1958-1972) and were collected from research stations in the SSRB of Alberta, from the Eastern Irrigation District records, and from various publications of Alberta Department of Agriculture. Water diversion figures were obtained from the Water Survey of Canada.[6]

In the first instance, the data were classified and tabulated for the EID. Information regarding acreage distribution by crop was obtained from the annual reports of the EID. Data for weather conditions (temperature, daytime hours and precipitation) were gathered from monthly weather reports. Information on water losses was found to be insufficient; therefore, no calculations were made to estimate water losses as these were included as part of gross water diversions. Calculations were made to estimate consumptive use requirements for different crops using a formula discussed in Chapter IV.

---

[6] R. E. Kerber and C. P. Robinson, "Return Flow Report for Irrigation Districts in Alberta," Water Survey of Canada (Calgary, Alberta: Inland Waters Directorate, Department of the Environment, 1972).

CHAPTER II

THEORETICAL FRAMEWORK OF WATER DEMAND

BASIC CONCEPTS AND DEFINITIONS

In economic terms the demand for water is defined as: "the amount of water or waste assimilation services for which individuals would sacrifice resources rather than go without." This sacrifice may be either:

a. in terms of the amount they are prepared to pay for the water or for the waste assimilation services, i.e., the price, or

b. the opportunities they are willing to forego in order not to use the resources.[1]

Demand for irrigation water is a function of the value of productivity of water. In other words, it is the marginal value product. To arrive at water demand, production functions are developed to relate variable inputs to production responses and product prices. For any production process, the unique relationship between output and input is referred to as the "production function" for that process. In developing production responses, it is assumed that producers buy and sell products in purely competitive markets. First, a production process involving one variable input is discussed and then a production process with two or more variable inputs is considered. A production function can be expressed in mathematical terms:

---

[1] W. R. Derrick Sewell, et al., Forecasting the Demand for Water (Ottawa: Policy and Planning Branch, Mines and Resources, 1968), p. 8.

$$Q = f\ (X_1, X_2) \ldots\ldots\ldots\ldots\ldots (2.1)$$

where Q is the quantity of output produced over some period of time, and X_1, X_2 are the quantities of inputs, i.e., water and land, employed in producing this output. The total productivity of X_1 in the production of Q is defined as the quantity of Q that can be secured from the input of X_1. If X_2 is assigned the fixed value X_2^0, then,

$$Q = (X_1, X_2^0) \ldots\ldots\ldots\ldots\ldots (2.2)$$

The input level X_2^0 is treated on a parameter, and Q becomes a function of X alone.

The production decision regarding the amount of variable inputs to be used hinges on the law of diminishing return, which states: if the input of one resource is increased by equal increments per unit of time while the inputs of other resources are held constant, total product will increase, but beyond some point the resulting output will become smaller and smaller. Considering X as variable input and holding other variables fixed, the total product curve in Figure 2.1 shows the output trend.

Average and marginal products of X_1 are defined in an analogous manner for particular values of X_2^0. The average product (AP) of X_1 is its total product (TP) divided by its quantity:

$$AP = \frac{Q}{X_1} = \frac{F(X_1,\ X_2^0)}{X_1} \ldots\ldots\ldots\ldots\ldots (2.3)$$

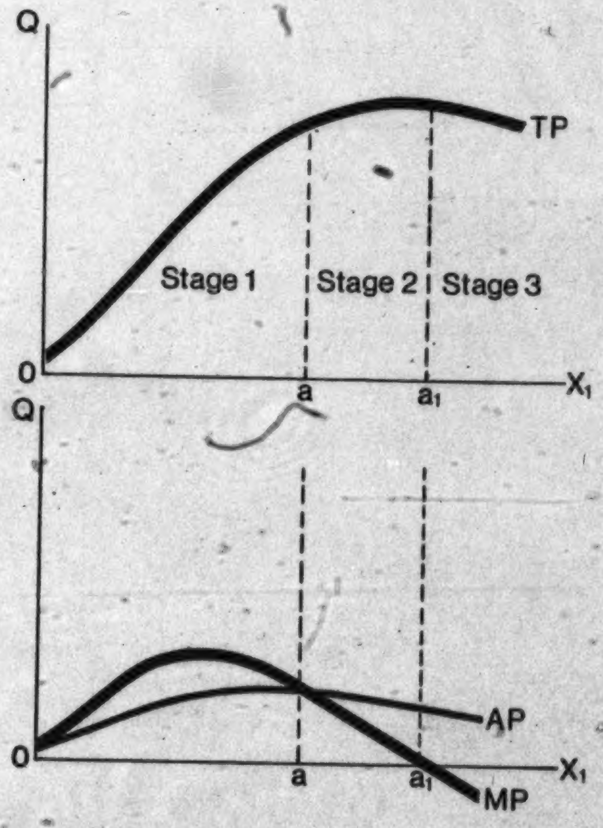
The marginal product (MP) of X_1 is the rate of change of its total product with respect to variations of its quality, i.e., the partial derivatives of (2.1) with respect to X_1:

$$MP = \frac{\delta Q}{\delta X_1} = F(X_1,\ X_2^0) \ldots\ldots\ldots\ldots\ldots (2.4)$$

Both AP and MP increase and then decline as the application of X_1 is increased.

Figure 2.1

Average and Marginal Products and Stages of Production



In Figure 2.1 the best resource use occurs in Stage II between a and a_1 units of X_1. The profit will be maximized where the value of MP produced by the incremental input equals the price of input.

The output elasticity of X_1, denoted by W, is defined as the proportionate rate of change of Q with respect to X_1:

$$W_1 = \frac{\delta(\log Q_1)}{\delta(\log X_1)} = \frac{X_1}{Q}\,\frac{\delta Q}{\delta X_1} = \frac{MP}{AP} \quad \ldots\ldots\ldots \quad (2.5)$$

Output elasticities may be expressed as ratios of marginal and average products and are positive if MP and AP are positive. The output elasticity of an input will be greater than, equal to or less than unity as its MP is respectively greater than, equal to, or less than its AP.

PRODUCTION FUNCTION WITH TWO VARIABLE INPUTS

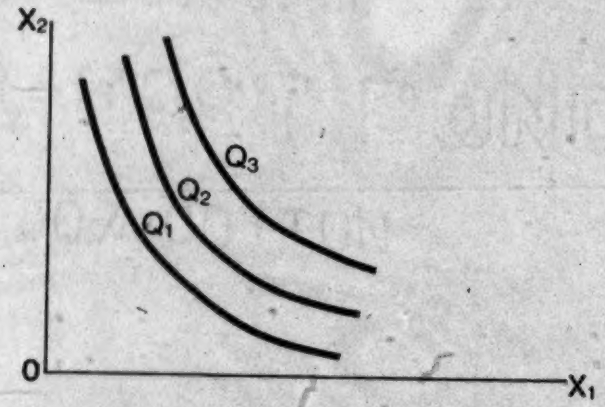
A production function with two variable inputs is used to determine the output when quantities of both variable inputs are increased or decreased or when one variable is substituted for another. The production function for two variable inputs is:

$$Q = F(X_1\ X_2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.6)$$

where Q is the amount of product and X_1,X_2 are amounts of variable inputs; i.e., land and water. The locus of all the combinations of X_1 and X_2 which satisfy equation 2.6 forms an isoquant. Since the production function is continuous, an infinite number of input combinations lie on each isoquant. All the input combinations which lie on an isoquant will result in the output indicated for that curve (Figure 2.2). The farther an isoquant lies from the origin, the greater the output level which it represents.

Figure 2.2

Isoquants Showing Different Combinations of Inputs



The slope of the tangent to a point on an isoquant is the rate at which X_1 must be substituted for X_2 (or X_2 for X_1) in order to maintain the corresponding output level. The negative slope is defined as the rate of technical substitution (RTS):

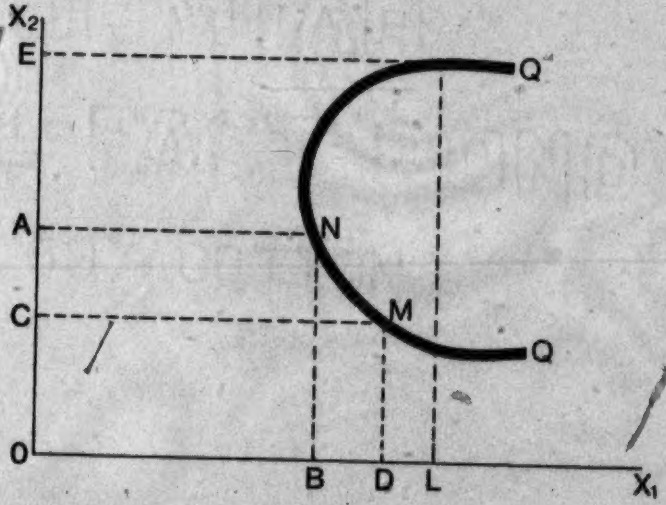
$$RTS = \frac{\delta X_2}{\delta X_1}.$$

If a production function has convex isoquants, the RTS of X_1 for X_2 will decline as X_1 is substituted for X_2 along an isoquant. A rational profit maximizing producer would never use the combination of variable inputs OL of X_1

and OE of X_2 (Figure 2.3) as there are other combinations requiring less of both inputs which will produce the same output. For a rational producer the choice occurs along NM segment of the isoquant.

Figure 2.3

Production Function with Two Variables



Considering the production function (2.6), the producer will try to produce Q as cheap as possible. This means the producer is trying to minimize the cost of producing a prescribed level of output. The cost is given by:

$$C = r_1 X_1 + r_2 X_2 + \dots = r_n X_n \quad \dots\dots \quad (2.7)$$

where r_1 is the cost of input 1 and r_2 is the cost of input 2.

Now using Q as one of the inputs, the enterpreneur's explicit production function could be states as:

$$Y = Q^m X^n, \quad \dots\dots\dots\dots \quad (2.8)$$

$$\text{Total Cost} = C = r_1 Q + r_2 X. \quad \dots\dots \quad (2.9)$$

By transforming (2.8) into a linear logarithmic function:

$$\log Y = m \log Q = n \log X. \dots\dots\dots \quad (2.10)$$

Assuming perfect competition, the producer's profit function is:

$$\pi = PY - r_1 Q - r_2 X. \dots\dots\dots \quad (2.11)$$

To maximize the producer's profit function subject to its production functions, we use a Lagrangian function and derive first order conditions for profit maximization.

$$\pi\lambda = PY - r_1 a - r_2 X + \lambda(\log y - m\log Q - n\log X). \quad (2.12)$$

Setting the partial derivatives equal to zero, we in turn obtain:

$$\delta\pi\lambda = P + \lambda = 0 \rightarrow P = -\lambda \dots\dots\dots \quad (2.13)$$

$$\frac{\delta\pi\lambda}{\delta Q} = -r_1 - \frac{\lambda m}{Q} = 0 \rightarrow Q = \frac{\lambda m}{r_1} \dots\dots\dots \quad (2.14)$$

$$\frac{\delta\pi\lambda}{\delta X} = -r_2 - \frac{\lambda n}{X} = 0 \rightarrow Q = \frac{\lambda n}{r_2}. \dots\dots\dots \quad (2.15)$$

Substituting P for λ in (2.14), the demand function for Q is obtained by:

$$Q = \frac{Pm}{r_1}. \dots\dots\dots \quad (2.16)$$

The demand for Q will increase as the price of the finished product increases and vice versa. Moreover, there is an inverse relationship between Q and its own price, r_1. This demand function is homogeneous of degree zero in P and r, and its elasticity with respect to its own price can be determined by using the formula:

$$\frac{r_1}{EQ} = \frac{dQ}{dr_1} \cdot \frac{r_1}{Q} \quad \ldots\ldots\ldots\ldots\ldots \quad (2.17)$$

DERIVED DEMAND FOR WATER

Demand for water is a derived demand, it largely depends on the demand for farm output. In the previous section, production functions with different input levels and derived demand were presented. Now, the demand for water is derived specifically.

The production function is:

$$Q = f\ (W, K)$$

where W is the amount of water used and K is the amount of capital required to produce Q. The producer trys to produce Q at a minimum cost. The producer's explicit function is stated as:

$$Q = W^X K^B \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.18)$$

and total cost is:

$$C = P_1 W + P_2 K \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.19)$$

where P_1 and P_2 are prices of inputs.

Transforming the production function (2.18) into a linear logarithmic function:

$$\log Q = X \log W + \beta \log K \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2.20)$$

and assuming perfect competition, the producer's profit function is:

$$\pi = PQ - P_1W - P_2K \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2.21)$$

where P is the price of output.

Performing the Lagrangian function and to derive first order conditions for profit maximization:

$$\pi\lambda = PQ - P_1W - P_2K + \lambda(\log Q - X \log W - \beta \log K). \quad (2.22)$$

Setting the partial derivatives equal to zero result in:

$$\frac{\delta\pi\lambda}{\delta Q} = P + \lambda = 0 \rightarrow P = -\lambda \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2.23)$$

$$\frac{\delta\pi\lambda}{\delta W} = -P_1 - \frac{\lambda\alpha}{W} = 0 \rightarrow Q = \frac{\lambda\alpha}{P_1} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2.24)$$

$$\frac{\delta\pi\lambda}{\delta K} = -P_2 - \frac{\lambda\beta}{K} = 0 \rightarrow Q = \frac{\lambda\beta}{P_2} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2.25)$$

Substituting P for λ in (2.24), we obtain a derived demand function for W, which is expressed as:

$$W = \frac{P\alpha}{P_1} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2.26)$$

and, similarly, (2.26) could be expressed as:

$$K = \frac{P\beta}{P_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.27)$$

The demand for "W" (water) will increase as the price of output (Q) increases and the demand for "W" will decrease if the price of output decreases. It represents a positive relationship between the demand for water and the price of output. Moreover, there is an inverse relationship between "W" and its own price, P_1.

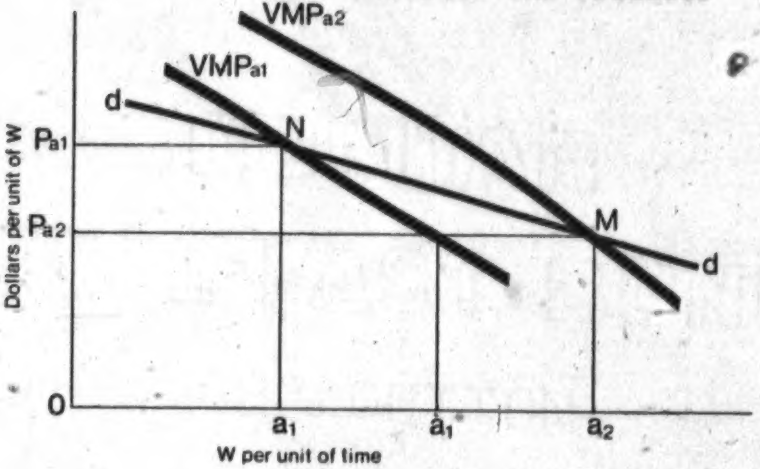
When a producer uses several variable resources, substitution of one for the other is possible. As in the above case, substitution of "W" for K or vice versa will shift the demand curve. In the case of several variable resources, the demand curve for any one of them is no longer the value of marginal product of the resource. A change in the price of one, assuming the prices of others remain constant, will bring changes in the quantities of the other resources, and these changes will in turn affect the utilization of the one which experienced a price change as the producer attempts to maximize profits and reestablish a least-cost combination of resources.

Suppose one wants to derive the producer's demand curve for resource "W", which is one of several variable resources. Suppose that initially the producer is producing Q output and is using the appropriate least-cost combination of variable resources. As shown in Figure 2.4, the price of

"W" is Pa_1, and quantity employed is a_1. The $VMPa_1$ curve shows the value of the marginal product of W when only the quantity of W is varied.

Figure 2.4

Demand Curve of the Producer



Source: Richard H. Leftwich, The Price System and Resource Allocation, 4th edition (Illinois: The Dryden Press Inc., 1970), p. 289.

Now suppose that for some reason the price of W falls to Pa_2. Since $VMPa < Pa$, the producer will expand employment of W towards a_1. However, the increased utilization of W will shift the marginal physical product and the value of marginal product curves of variable resources complementary to W to the right. The corresponding curve of substitute resources will be shifted to the left. Since prices of other resources will increase while that of substitute resources will decrease. Such changes in the utilization of other resources will shift the MPP and VMP curves of W to the right. When these and higher order complementaty and substitute effects have worked themselves out, the producer will be on a VMP curve similar to $VMPa_2$ and will be employing that quantity of W at which its VMP equals its price, i.e., quantity a_2.

Points N and M are points on the producer's demand curve for resource W. These points show the quantities of W that the producer would take at alternative prices of W when the prices of other resources are held constant and quantities of all other resources are adjusted appropriately for each price of W. Other points on the Producer's demand curve for W can be established in a similar fashion and would trace a curve such as dd. Ordinarily, the producer's demand curve for a resource will be more elastic than will any single value of a marginal product curve of the resource. The better the substitutes available for a resource, the more elastic its demand curve will be.

THE MARKET DEMAND CURVE

In a purely competitive situation, an individual producer is small enough relative to the markets in which he operates to anticipate that his actions will have no effect on the price of anything he buys or sells. Similarly, the producer anticipates that his actions will have no effect on the price of product sold. The producer considers resource price changes only. Moreover, the market demand curve for a resource is the horizontal summation of individual producers' demand curves.

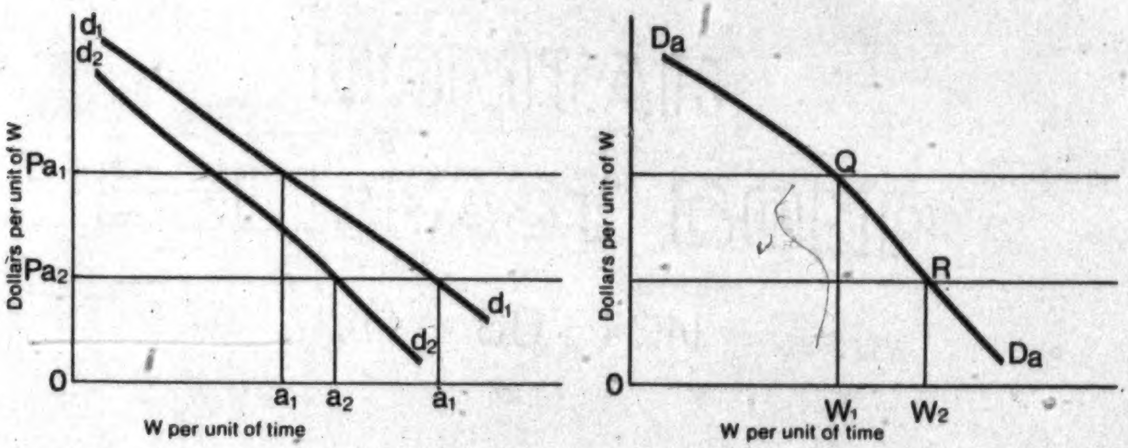
A simultaneous expansion or contraction of industry outputs of products is brought about by all producers using a given resource as the price of that resource changes. A decrease in the price of resource W will cause all producers using W to increase their employment of it although no one producer's increase in output is sufficient to cause a decrease in the price of the output of the whole industry.

There are some external market factors which bring changes in the price of a resource and the construction of the market demand curve. Suppose that the producer of the diagram (Figure 2.5) and every other producer who uses resource W is in equilibrium and the price of W is Pa_1. The producer's demand curve for W is d_1d_1 and the producer is employing a_1 of W. By summing the amount which all producers employ at price Pa_1, the total amount taken off the market at that price is W_1. Thus, Q is a point on the market demand curve for W.

Now suppose price of W falls to Pa_2. Each producer will expand his employment of W, but as other producers in an industry expand employment of W, the market prices for products decrease. Individual producer's demand curve for resource W shift to the left (i.e., d_2d_2). Thus, the individual producer employment levels of W will increase towards such quantities as a_2 rather than a_1. Restricted expansion in the employment of W results from the market or external effect of the decrease in resource price. To achieve a least-cost combination of resources and to maximize profit, the producer's employment level is a_2, the amount employed at price Pa_2. This amount can be totaled for all producers to obtain quantity W_2, and R is a second point on the market demand curve for W. Other points on the market demand curve can be found in a similar way to trace out market demand curve Da Da.

Figure 2.5

The Market Demand Curve



WATER DEMAND FOR THE EASTERN IRRIGATION DISTRICT

Water rates in the Eastern Irrigation District are charged on a flat rate basis. As discussed in the previous sections, demand for water is a derived demand and is based on product prices. If the prices of output increase, more land will be brought under irrigation to obtain higher returns. Besides output prices there are factors which would effect water use due to substitution of one input for another. The marginal value product of irrigated land can be estimated by taking the value of farm products sold, dividing them by the irrigated acreage, and multiplying the result by the productivity coefficient of irrigated acreage. The marginal value product of irrigated land measures the changes in the value of total output. The MVP of current operating expenses measures the variation in the value of total output that results from varying the use of current operating expenses. If the MVP of a particular input exceeds the cost of additional units of that input to the production process, net returns can be improved by expanding the use of the particular input. If the MVP of a particular input is less than the cost of adding additional units of that input to the production process, net returns can be improved by reducing the use of the particular input. Application of this principle may require reduction in the use of some inputs, expansion in the use of other inputs, and changes in the level of output in order to achieve an appropriate balance or equilibrium among input levels and between input and output levels.

In the area under study, the marginal cost for applying additional water is assumed to be zero (nil labour costs). A rational farmer would apply water to the point where he could get maximum returns. Farmers in the Eastern Irrigation District are legally bound to pay flat rate charges if they have obtained water rights. The farmers in this area apply the maximum amount of water to obtain higher returns. However, demand for water is affected by changes in output prices which are again related to acreage irrigated. Data regarding output prices and other economic factors were not readily available for relation to water demand; hence, acreage irrigated and other physical factors have been substituted to anlayse this relationship. In this substituting situation, water use is now related to acreage irrigated, irrigation requirements of crops, weather conditions and precipitation during the pre-growing season rather than to output prices, production costs and other economic factors. On the basis of above variables, a regression model has been developed to analyse irrigation water use in the area under study.

CHAPTER III

IRRIGATED AGRICULTURE IN THE EASTERN IRRIGATION DISTRICT

Irrigation has been practiced in Southern Alberta since before the turn of the century. Expansion has occurred over the years until at present there are 750,000 acres of irrigated land which produce approximately 20 percent of Alberta's gross agricultural output each year. The irrigated land in Southern Alberta constitutes approximately 4 percent of the Province's total improved arable land.[1]

The Eastern Irrigation District is the largest of the 14 irrigation districts in Souther Alberta. The total area of the District is 1.446 million acres and the irrigated acreage accounts for 37 percent of the irrigated land in the Province. The main crops grown by the earlier settlers were flax, wheat, oats and alfalfa seed.[2]

When the District was created in 1935, a survey showed that not over 90,000 acres were being irrigated. The number of irrigated acres had increased by 1960 to slightly over 190,000 and further increased to over 200,000 acres in 1971. In many instances farmers themselves developed more land by levelling adjacent rough areas, and in other instances, the District made land available by rebuilding old ditches and constructing new ditches.[3]

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[1] E. H. Hobbs, "Consumptive Use of Water Studies in Southern Alberta" (paper presented to the Agassiz Center for Water Studies, University of Manitoba, Winnipeg, Manitoba, March 19, 1969), p. 1.

[2] Board of Trustees, The History of the Eastern Irrigation District--25th Anniversary, May 1st, 1960 (Brooks: Board of Trustees, Eastern Irrigation District, 1960), pp. 27-28.

In the Eastern Irrigation District 62 percent of the cropland in farms was under irrigation in 1963. A substantial portion of crop and livestock production is attributed to irrigation. The distribution of land acreage in this district stands as follows:[4]

i)	Irrigated-Cultivated	190,600 acres
ii)	Dryland-Cultivated	113,000 acres
iii)	Irrigated Range	1,700 acres
iv)	Dryland Range	1,140,700 acres
	TOTAL	1,446,000 acres

The potential area for irrigation in the EID is about 281,000 acres. The area now under irrigation is more than 70 percent of the potential area.

The climate in this area is boreal, characterized by long winters and short but pleasantly warm summers.

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[3] *Ibid.*, pp. 28-30.

[4] Walter B. Rogers, Travis W. Manning and Herbert W. Grubb, *The Economic Benefits and Costs of Irrigation in the Eastern Irrigation District of Alberta*, Alberta Irrigation Studies, Vol. V; Agricultural Economics Research Bulletin 3, (Edmonton: Dept. of Extension, University of Alberta, May 1966), p. 31.

Snow covers the ground for only short periods of time, partly as a result of chinook effects. The normal dry weather of early spring favors seeding operations while the rains of June and July usually provide moisture to maintain growth.

The land in the EID is fertile and suitable for diversified crop production. The prevailing soil classification is brown podzolic. The upper land of the soil profile is commonly brownish in color and the lime layer is found at depths of 14 to 24 inches. The native vegetation is short prairie grass. The brownish and dark brown soils are heavy soils and among the best wheat soils of Canada.[5] Brown soils are generally used for wheat production and cattle ranching.

The Eastern Irrigation District lies in an area which is classified as semi-arid; annual average precipitation is 13.28 inches. Rainfall from May to September accounts for 62 percent of the average total rainfall. However, the predominance of the rainfall during the growing season does not eliminate the problem of drought. Drought occurs when the amount of moisture needed for plant transpiration, the run off loss and losses through evaporation are greater than the total amount of natural rainfall.

AGRICULTURAL PRODUCTION IN THE EASTERN IRRIGATION DISTRICT

The farmers in the District use irrigation water, paying on a flat rate basis irrespective of the amount of water used. The present rate is $3.00 per irrigable acre. When a farmer's land is classified as irrigable and he obtains a water right, he pays the above rate, whether he uses water or not. However, irrigation has played a significan role in enhancing agricultural production in the EID and in other areas as well.

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[5] *Ibid.*, p. 3.

The irrigated acreage in the District in 1972 shows an increase of about 20 percent over the area in 1958 (Appendix Table 4). The crops which occupy the major share of the irrigated acreage are alfalfa, wheat, barley and oats. A considerable area is under summer fallow and pasture in the Eastern Irrigation District.

In the EID, wheat occupied about 15 percent of the total irrigated area in 1958, decreasing to 12 percent in 1972. Some years there were major shifts in acreage from wheat to other cereal crops (Appendix Table 14). Similarly, a downward trend has been observed in the case of oats. The area under oats was more than 22,000 acres in 1958 (i.e., about 16 percent) and it decreased to 14,605 acres in 1972. The area occupied by barley increased from 18 percent of the total irrigated area in 1958 to 23 percent in 1972. A major shift has also been observed in the area under alfalfa hay. Alfalfa, which covered 40,785 acres in 1958, increased to 57,559 acres in 1972. This crop covers about 36 percent of the total irrigated area in the EID.

Water use (gross water diversions) in acre-feet and acreage under different crops in the EID from 1958 to 1972 are presented in Appendix Table 14. Range and average acreage occupied by different crops during the period 1958-1972 are presented in Table 3.1. The table reflects considerable fluctuations in acreage of various crops and in the total acreage covered by such crops.

Table 3.1

Range and Average for Water Diverted and Area Irrigated for Various Crops in the Eastern Irrigation District (1958-72)

Description	Range	Average
Water diverted (acre-feet)	349,000 to 652,000	481,109
Wheat (acres)	10,387 to 29,186	20,974
Flax (acres)	2,053 to 13,935	8,350
Oilseeds (acres)	7 to 837	244
Oats (acres)	11,549 to 23,094	16,912
Rye (acres)	55 to 864	358
Alfalfa seed (acres)	332 to 2,814	1,129
Clover Hay (acres)	110 to 3,009	1,214
Clover seed (acres)	10 to 496	184
Small seeds (acres)	238 to 3,002	1,198
Grass (acres)	513 to 1,425	811
Mixed grains (acres)	3,547 to 6,510	4,967
Green feed (acres)	2,496 to 9,450	5,016
Barley (acres)	14,868 to 43,722	28,750
Peas (acres)	1,136 to 6,289	3,155
Potatoes (acres)	1,387 to 5,003	2,972
Corn (acres)	495 to 1,374	864
Alfalfa hay (acres)	31,363 to 57,559	46,108
Total Area Irrigated (acres)	129,348 to 158,976	143,849

Source: The Board of Trustees, Eastern Irrigation District, Brooks, Alberta, Annual Report (Brooks: EID Board of Trustees, 1958-72). (Printed by the Brooks Bulletin, Brooks, Alberta.

CHAPTER IV

METHOD OF ANALYSIS

The regression analysis technique was applied to study past behavior and the relationship between the identified variables. By no means unique to forecasting regression analysis is a very useful statistical tool which can be used in a wide varietyof analytical situations. Regression analysis refers to the technique involved in deriving an equation by which one of the variables--the dependent variable--may be estimated from other variables--the independent variable.

Regression analysis has two main purposes:

1. To construct an equation which would enable estimation of the value of the dependent variable from the given values of independent variables.
2. To measure the closeness of the relationship between the variables.

Multiple regression analysis involves more than one independent variable at a time. Generally when two or more independent variables are considered jointly, the estimating procedure is far more accurate than when only one independent variable is used. The coefficient of multiple correlation and the related coefficient of multiple determination measure the closeness of the relationship between the dependent variable and the joint simultaneous configuration of the independent variables.[1]

The estimating equation produces estimates of X_1 (the dependent variable) from given values of other indpendent variables. If, for example, there are three independent variables in the problem, the equation is:

$$X_1 = a + b_2X_2 + b_3X_3 + b_4X_4.$$

The symbols used are a simplification of a more elaborate and more precise system which would represent the equation as:

$$X_1 = a_{1(234)} + b_{12.34}X_2 = b_{13.23}X_3 + b_{14.23}X_4.$$

In this sytem:

$X_{1(234)}$ = the value of X_1 estimated from the multiple regression in which X_2, X_3 and X_4 are the independent variables,

$b_{12.34}$ = the coefficent of X_2 in the multiple regression equation in which X_1 is the dependent variable, and X_2, X_3 are also in the equation. It is called the coefficient of partial or net regression.[2]

Regression analysis can often be misused, especially with modern computing machinery. It is all too easy to take a "black box" approach and throw all available data into the hopper and then try all combinations to see which is "best". Regression analysis is used in the construction of a formal model which can serve the purpose. Without some kind of model, the output of regression analysis is nothing more than a collection of numbers, and interpretation is impossible.[3] Once constructed, a model needs to be tested by empirical analysis.

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[1] Samuel B. Richmond, Statistical Analysis, Second Edition (New York: The Roland Press Company, 1964), p. 424.

[2] Ibid., p. 447.

MODEL DEVELOPMENT

In choosing a model for planning, not only must the statistical attributes of the model be taken into account but also the availability of data. A model which provides good statistical estimation would be worthless to planners if it is impossible to obtain the information required. Keeping this in mind, a regression analysis technique has been applied in this study. It used the relationship between factors such as water use (gross water diversions) as the dependent variable and consumptive use requirements for crops, acreage irrigated for each crop, weather conditions and precipitation during the pre-growing season as the independent variables. This model describes a mathematical relationship between the variables mentioned.

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[3] Chisholm and Whitaker, Forcasting Methods (Homewood, Illinois: Richard D. Irwin, Inc., 1971), pp. 94-97.

The steps followed in the development of the model are discussed in the following sections. First, a formula was developed to calculate evapotranspiration for different crops in the EID. When the precipitation for the crop season was deducted from evapotranspiration, irrigation requirements were obtained for each crop. The "K" (monthly consumptive use coefficient) values for various crops were obtained from the United States Department of Agriculture publication, Determining Consumptive Use and Irrigation Water Requirements,[4] and are presented in Appendix Table 1.

Secondly, the crops were grouped together according to their management pattern, acreage and irrigation requirements. Grouping helped to reduce the calculations and to minimize errors.

The calculated consumptive use requirements for different crops are presented in Appendix Tables 3 to 12. After calculating these figures, the area irrigated for each crop was multiplied by the respective net consumptive use requirements in order to arrive at the water requirements during the growing season. The grouping was done by simple addition of the calculated water requirement figures for the respective crops in each group. For example:

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[4] Blaney and Criddle, Determining Consumptive Use and Irrigation Water Requirements, Technical Bulletin No. 1275 (Washington: Agricultural Research Service, USDA, December 1962), pp. 49-52.

Group I = (Area irrigated for wheat X net consumptive use for wheat + area irrigated for flax X net consumptive use for flax) + . . . + (Area irrigated for canary seed X net consumptive use for canary seed).

The figures for other groups of crops were similarly calculated.

The regression model formulated for analysing past trends of the variables specified and for water use analysis in the EID took the form:

$$W = f\ (X_1, X_2, X_3, X_4, X_5, X_6, E$$

where:

W = gross water diversions (water use) for irrigation in the Eastern Irrigation District;

X_1 = Water requirements during the growing season for the crops in group I;

X_2 = Water requirements during the growing season for crops in group II;

to

X_5 = Water requirements during the growing season for the crops in group V;

X_6 = Precipitation during the pre-growing season;

E = Random error term.

Evapotranspiration

Evapotranspiration[5] is influenced by temperature, irrigation practices, length of the growing season, precipitation, humidity of the air, wind movement, intensity and duration of sunlight, stage of development of plant, type of foliage and nature of the leaves. Evapotranspiration is an important factor which directly affects the water supply for irrigation purposes. At some places in the area under study (e.g., Brooks), it leads to a moisture deficit of 24 inches in the case of grass and 23 inches in the case of alfalfa.[6]

In 1963, Underhill[7] conducted a study on irrigation water use in the Province of Alberta. The approach to the problem was to determine the amount of water required in evapotranspiration or consumptive use. He indicated that for every change in location, a different amount of water was required, depending on various climatic and soil conditions. Further, he observed that it was difficult to decide on the amount of water required for a project because of lack of data on which to base calculations.

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[5] Evapotranspiration is the sum of two terms: (i) Transpiration, which is water entering plant roots and building plant tissue then being passed through the leaves of the plant into the atmosphere; (ii) Evaporation, which is water evaporating from adjacent soil, water surfaces or from the surfaces of the leaves of the plant. Water deposits by dew, rainfall or irrigation and subsequently evaporating without entering the plant system is part of the consumptive use.

[6] Figures obtained from the Regional Office of the Alberta Department of Agriculture, Lethbridge, Alberta.

[7] A. G. Underhill, Report on Irrigation Water Use Study (Edmonton, Alberta: Government of Alberta, Department of Water Resources, October 1963).

Underhill suggested that calculations be divided into four main parts:

1. Water required for plant consumptive use,
2. Water required to supply the losses encountered at the farm level, i.e., deep percolation, waste and evaporation,
3. Water required to supply the losses incurred in carrying the water from the point of diversion through the canals and reservoirs to the point of delivery to the farm unit,
4. The water returned to the stream or adjacent streams for use downstream.[8]

The total requirements or gross diversion to a project is the sum of the plant consumptive use, farm efficiency and the conveyance losses. The net depletion from the stream is gross diversion minus the return flow.

The water used by a crop may come from any one or all of four sources:

1. Precipitation,
2. Soil moisture,
3. Ground water,
4. Irrigation water.

When making an estimate of the water required for irrigation, one needs to know the actual consumptive use of the plants together with the water available due to precipitation, soil moisture and ground water. When these factors are all available, one can determine the irrigation requirements of a crop.

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[8] *Ibid.*, p. 1.

Underhill used most of the empirical formulae developed to date to determine the consumptive use rate. He mentioned that these formulae take into account one or more of the climatic factors. Temperature, precipitation, evaporation, relative humidity, radiation, and hours of sunshine, etc. are generally considered to have the greatest effect on plant water requirements. Other factors which affect plant water requirements are soil, topography and water supply. He suggested that in using these empirical consumptive use formulae, judgment is necessary in the selection of the formula best suited to the area under consideration. The formulae will use the measured meteorological data available for the area.

The following methods are listed by Underhill for calculating consumptive use:

1. Actual measurements,
2. Blaney-Criddle Method,
3. Lowry Johnson Method,
4. Penman Method,
5. Thornthwaite Method,
6. Oliver Method,
7. Hargreaves Method, and
8. Atmometer Method.[9]

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[9] *Ibid.*, p. 18

On the basis of data available, he selected the three methods enumerated below because in the Prairie Provinces the only meteorological data generally available for an area are temperature and precipitation. This means that to be usable, a formula must be based on these two factors.

The empirical formulae using these data were:

1. Blaney-Criddle Method,
2. Lowry Johnson Method, and
3. Thornthwaite Method.

Of these three, only the Blaney-Criddle formula uses the crop coefficients of individual crops. Underhill preferred to use the Blaney-Criddle Method for calculating the consumptive use rate. His preference for this method was based on the results he obtained and was also due to a general acceptance of the method by the United States Bureau of Reclamation, U.S. Department of Agriculture and the U.S. Army Engineers, as well as the states of Montana, Idaho, North Dakota and the province of Saskatchewan.

For the present study, evapotranspiration or consumptive use figures were developed using the Blaney-Criddle Method. Blaney and Criddle assumed that consumptive use varies with temperature, length of day, and available moisture, regardless of its source (precipitation, irrigation water or natural ground water). Multiplying the mean monthly temperature (t) by the possible monthly percentage of daytime hours of the year (p) gives a monthly consumptive use factor (f). Blaney and Criddle assumed that crop consumptive use varies directly with the factor when an ample water supply is available.[10] Research data have made possible the determination of a seasonal coefficient (K) for different crops. K is the summation of the monthly consumptive use coefficents (k).

Expressed mathematically:

$$U = K\Sigma pt = KF$$

where:

U = Consumptive water requirement in inches for any period of time (usually growing season),

K = Consumptive use coefficent (annual, irrigation season or growing season),

F = Sum of the consumptive use factors of the period (sum of the products of mean monthly temperature during the period and percentage of annual daytime hours in the period) $(t \times p)/100$,

t = Mean monthly temperature in degrees Fahrenheit,

p = Percentage of daytime hours occurring during the period;

For monthly calculations, lower case letters are frequently used:

f = Monthly consumptive use factor; $(t \times p)/100$, k = Monthly consumptive use coefficient,

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[10] Orson, W. F. Israelsen and Vaughn E. Hansen, Irrigation Principles and Practices (New York: John Wiley & Sons, Inc., 1962), pp. 252-253.

u = kf = Monthly consumptive use in inches.

Precipitation

The amount and rate of precipitation may have some effect on the amount of water used during the growing season. Under certain conditions, precipitation may occur as a series of frequent, light showers during the hot summer. Such showers may add little or nothing to the soil moisture for use by the plants through transpiration but they do decrease withdrawal of stored moisture. Such precipitation may be lost mainly by evaporation directly from the surface of the plant foliage and the land surface.

The available soil moisture through precipitation may substantially reduce the amount of irrigation water needed. Various methods have been used to estimate effective precipitation under different climatic soil and crop conditions. Table 4.1 shows one of the methods used.[11] To arrive at net consumptive use requirements for the crop, the effective precipitation was deducted from the gross water requirements of that crop. These net consumptive use requirements were calculated with emphasis on the length of growing season (varies for different crops). The calculated values for each month were accumulated to obtain seasonal consumptive use

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[11] Harry F. Blaney and Wayne D. Criddle, Determining Consumptive Use and Irrigation Water Requirements, Technical Bulletin No. 1275 (Washington, D.C.: U.S.D.A.), p. 13.

Table 4.1

Total and Effective Monthly Precipitation

Possible Monthly Precipitation (inches)	Monthly Rainfall Considered Effective	
	Part of Each Inch Increment	Accumulated Total
1	0.95	0.92
2	.90	1.85
3	.82	2.67
4	.65	3.32
5	.45	3.77
6	.25	4.02
Over 6	.05	----

NOTE: Effective precipitation is defined as precipitation falling during the growing period of the crop that is available to meet the consumptive water requirements of crops. It does not include deep percolation below the root zone nor surface run off.

figures.

Crop Grouping

The crops grown in the Eastern Irrigation District were divided into five groups. The criteria used to group the crops were the management patterns, acreage and the consumptive use requirements. Efforts were made to place all crops with similar characteristics into one group. The logic in grouping crops was smaller number of observations. Fewer observations and limited data made it difficult to include each crop separately in the model development. Moreover, lack of observations and data would have resulted in a model too complex for this study. Grouping helped to condense the model.

The grouping of crops is as follows:

Group I	-includes wheat, flax, mustard seed, rapeseed, sunflower seed and canary seed;
Group II	-includes oats, rye, mixed grains and green feed;
Group III	-consists of barley only;
Group IV	-includes peas, corn, potatoes, turnips, parsnips and other vegetables;
Group V	-includes alfalfa hay, alfalfa seed, clover hay, clover seed, grass, and small seeds.

Economic Factors for Changes in Acreages

The model developed in the previous sections was based on water used for irrigation in the Eastern Irrigation District as the dependent variable, and acreage under irrigation for different crops, irrigation requirements for different crops, weather conditions and precipitation during the pre-growing season as the independent variables. Acreage under each crop, as well as total acreage cropped in the District, showed considerable variation between 1958 and 1972. These changes can be attributed to the economic factors discussed below.

In Chapter II, efforts were made to relate water demand for irrigation to output ptices. An increase in the price of farm products would favor bringing additional land into use and would encourage more intensive use of acreas already in use. Similar changes would be observed in water use. Declining price levels, on the other hand, can force retrenching policies, shifts to lower use and sometimes land abandonment. These phenomena apply to the Eastern Irrigation District. Farmers make decisions on the basis of past years' experiences when they allocate land and other related inputs to different crops. They have to keep in mind the market situation for the crops that they produce.

In the district under study, crop substitution has taken place to a considerable extent. The shift of acreage from one crop to another may be explained by farmers being able to foresee relatively better returns from a particular crop to which the area is shifted. For some years total acreage declined over the previous year and in other years the opposite was true. Decline in acreage could be linked with relatively smaller returns and farmers leaving the land as summerfallow. When there was an increasing demand for farm products, the farmers cropped the available acreage and even brought marginal land under cultivation which increased the total acreage and production.

Another factor which could have caused variation of acreage in various crops is cost of production. If one crop requires more inputs than another and has relatively smaller returns, the farmer will allocate his land to that crop which brings greater net revenue. Along with the cost of production, the price of land also affects farmers' decisions when making plans for land allocation for different crops.

The model formulated for irrigation water use analysis did not take into account output prices and other substituting factors as the data were limited for such factors. Hence, the model was developed on the basis of some physical factors rather than on economic facotrs (see Chapter II). The important factors in the regression model for water use analysis are irrigation requirements of different crops, acreage irrigated under different crops, weather conditions during the growing season and precipitation during the pre-growing season.

CHAPTER V

THE ANALYTIC RESULTS

The various factors affecting water use have been discussed in the previous chapters. This chapter is devoted to a formal presentation of the water use analytical model, a brief discussion of the empirical technique used to test the hypothesis and finally the regression results.

The following is the hypothesized relationship between irrigation water use[1] as a dependent variable and each of the independent variables.

$$W = f(X_1, X_2, X_3, X_4, X_5, X_6, E) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5.1)$$

where:

W = Water use in acre-inches in the Eastern Irrigation District.

X_1 = Water requirements in acre-inches during the growing season for the crops in Group I (wheat, flax, mustard seed, rapeseed, sunflower seed and canary seed).

X_2 = Water requirements in acre-inches during the growing season for the crops in Group II (oats, rye, mixed grains and green feed).

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[1] Water use represents the gross water diversions in the EID.

X_3 = Water requirements in acre-inches during the growing season for the crop in Group III (barley only).

X_4 = Water requirements in acre-inches during the growing season for the crops in Group IV (peas, corn, potatoes, turnips, parsnips and other vegetables).

X_5 = Water requirements in acre-inches during the growing season for the crops in Group V (alfalfa hay, alfalfa seed, clover hay, clover seed, grass and small seeds).

X_6 = Precipitation during the pre-growing season.

E = Random error term.

The postulated a priori relationships stated in terms of partial derivates are as follows:

$$\frac{\delta W}{\delta X_1} > o, \ \frac{\delta W}{\delta X_2} > o, \ \frac{\delta W}{\delta X_3} > o, \ \frac{\delta W}{\delta X_4} > o, \ \frac{\delta W}{\delta X_5} > o, \ \frac{\delta W}{\delta X_6} > o \quad . . . (5.2)$$

EMPIRICAL REGRESSION MODEL

The goals of this research and the nature of the available data required an empirical technique that could estimate the influence of each of the independent variables on water use in the Eastern Irrigation District. An empirical technique was required which could take into account the simultaneous effects of all the variables.

Multiple regression was a suitable technique that could meet these criteria--it could sort out the effects that may have been masked in a simple one variable comparison and it could estimate which variables were significantly related to one another and the type and magnitude of their relationships.

The following discussion is based on the model developed for regression analysis. The overall test of the model was based on the F-statistic. The tests of the individual regression coefficients were based on the t-values. However, little emphasis was placed on the test of individual coefficients. The tests of significance were also based on the level of explained variation for individual groups as indicated by r^2-value. The multiple coefficient of determination (R^2) indicated that fraction of the total variation in the dependent variable associated with the variation in the explanatory variables. The Durbin-Watson statistic was used to test the evidence of serial correlation. Significance levels of 0.01 and 0.05 were set to test the regression coefficients of the equation. The regression coefficients indicate how much the dependent variable will change with the change in independent variables. The coefficients of the model were estimated by the ordinary least-squares method.

Essentially, there are four statistics on the basis of which the equation of "best fit" may be chosen. These are:

1. The multiple coefficient of determination (R^2) indicates the amount of total variation in the dependent variable associated with the variation in independent variables.

2. The F-value shows the rate of the explained variance to the unexplained (residual) variance.

3. The multiple standard error of the estimate measures the preciseness of prediction of the dependent variable on the basis of the independent variables.

4. The standard errors of the regression coefficients increased the degree of significance of the individual regression coefficients in the equation.

In a regression analysis the error from the equation may be attributed to:

1. measurement error;
2. imperfect or incorrect specification of the form of equation; and
3. the inherent irreproducibility of biological or social phenomena.[2]

The model for empirically testing the hypothesis in the preceding discussion was a linear regression model:

$$W = \beta X_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + E \quad . . . (5.3)$$

where:

X_0 denotes the intercept,

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[2] R. J. Wonnacott and T. H. Wonnacott, Econometrics (New York: John Wiley & Sons, Inc., 1970), p. 17.

β_1 to β_6 denotes regression coefficients,

E denotes the random error term.

The remaining symbols were the same as in equation (5.1).

The water use (dependent variable) figures were regressed against the independent variables and the results obtained are presented in Table 5.1. The independent variables explained 84 percent of the variation in water use. The variables X_2 and X_5 explained more than 67 percent of the total variation. The F-value was significant at the 0.01 level of significance.

The regression coefficients of X_5 and X_6 were significant at the 0.05 level of significance. The coefficients of X_1 and X_3 were significant at the 0.1 level of significance, and the coefficients of X_2 and X_4 were not significant at the 5 percent level. The latter two variables were not omitted from the model developed as these covered important crops which indicated considerable water use. The Durbin-Watson statistic indicated no auto correlation in the data.

The negative sign for the coefficient of the X_4, variable (peas, corn, potatoes, turnips, parsnips and other vegetables) was not expected because it indicated an inverse relationship between water use and the area under this group of crops. It should only happen in extreme cases and in unusual years when ther is enough rainfall to account for water required for these crops. However, the negative sign

Table 5.1

Regression Model Results

Variable	β-Coefficient	St. Error	t-Value	Variation
X_1	4.12263	2.1602	1.91	4.36
X_2	1.57364	2.1605	0.73	47.05
X_3	4.9714	2.6837	1.85	1.01
X_4	-13.6086	7.8982	1.72	6.06
X_5	5.3729	1.3703	3.92	20.28
X_6	- 3.14578	1.3508	2.33	4.93

X_0 = -130,438.695

R^2 = 83.68

F-value = 6.83

DW-statistic = 2.79

for this coefficient could be by chance or may be due to some unidentified factors.

The negative sign for the coefficient of the X_6 variable, i.e., precipitation, was expected as it would lead to a decrease in water use if the precipitation level was high during the pre-growing season.

The intercept has a large value with a negative sign. The sign may mean that the relationship between the variables could have been curvilinear, but in this study a linear relationship has been applied. A large intercept value does not fit in the range of regression line, and linear regression equations do not take into account such high values.

The β-coefficients of the regression equation explained a past relationship between the dependent variable and the independent variables. For example, β_1 indicated that, certeris paribus, as the water requirement for group I crops (wheat, flax, mustard seed, rapeseed, sunflower seed and canary seed) increased by one acre-inch, the total water use increased by 4.12 acre-inches. β_2 indicated that as the water requirement for group II crops (oats, rye, mixed grains and green feed) increased by one acre-inch, total water use increased by 1.57 acre-inches. β_3 exhibited that if water use for group III crops (barley only) increased by one acre-inch, it increased total water use by 4.97 acre-inches. Similarly, β_5 indicated that one acre-inch increase of water use for crops in group V (alfalfa hay, alfalfa seed, clover hay, clover seed, grass and small seeds) would increase total water use by 5.37 acre-inches. β_6, the coefficient for the precipitation variable (X_6) showed that one acre-inche increase of water during the pre-growing season, would decrease total water use by 3.15 acre-inches at the seeding time.

The model explained the past relationship between the dependent variable and the several independent variables. These relationships are expected to remain similar assuming all other factors remain the same. However, in case of variable X_4 where the relationship observed is negative, the future findings may contradict this unexpected relationship.

The model presented fulfills most of the conditions which a regression model should meet. The statistical tests show that the relationship between the variables are significantly different from zero. R^2 indicates that the amount of variation explained by independent variables to the dependent variable is significant. Hence, this model can be applied for irrigation water use analysis in the Eastern Irrigation District. The model developed for the EID can be suggested for water use analysis in other districts of the SSRB area, if information regarding independent variables is made available.

CHAPTER VI

SUMMARY

This study was concerned with water use analysis and the development of a regression model for water use projections in the South Saskatchewan River Basin of Alberta. It was initially proposed for the entire SSRB, but was eventually concentrated only on the Eastern Irrigation District due to data limitations.

A regression model was formulated relating water use for irrigation to acreage under irrigation, consumptive use requirements of different crops and to some measured weather conditions. Another independent variable representing precipitation during the pre-growing season was also incorporated in the model. It showed a significant effect on the dependent variable.

Consumptive use requirements for each crop were calculated using the Blaney-Criddle formula. The formula accounted for precipitation, temperature and daytime hours. Data for acreage irrigated were taken from the Annual Reports of the Eastern Irrigation District. Data for weather conditions were obtained from monthly weather reports.

All crops were divided into five groups, on the basis of acreage, consumptive use requirements and management. The major reason for grouping the crops was the small number of observations. The linear regression technique was applied to determine the relationship between the dependent variable and the independent variables. All the regression coefficients except X_2, and X_4 were significantly different from zero at specified levels of significance. Other tests for the model were also significant at the levels specified. The negative sign for the coefficent of the X_4 variable was not according to expectations and could be due to chance or some unidentified factors. However, the model presented fulfills most of the statistical conditions which a regression model should meet. Therefore, this model could be suggested for water use analysis in the area under study.

IMPLICATIONS OF THE STUDY

1. Despite the theoretical limitations which constrain the use of ordinary least-squares regression in demand analysis, the model could be relied upon to give valuable estimates for the future. All the variables in the model generate an effect significantly different from zero.

2. The technique attempts to identify the important variables constituting water use. The model could be further modified to analyse water use for each group of crops or each crop separately.

3. The study indicates that water use is greatly affected by precipitation during the pre-growing season.

4. The regression model explained satisfactorily the

relationships between the dependent variable and the independent variables. The model was statistically valid.

LIMITATIONS OF THE STUDY

The limiting factor in this study was lack of appropriate data. With respect to the data needed for development of functional relationships for analysing water use for irrigation, little direct information is systematically gathered on irrigation diversions, gross water application and irrigation efficiency, crop types, soil types, irrigation method, management practices, and irrigation and drainage costs. In the Eastern Irrigation District, data are available on diversions from major streams, but this information is seldom collected on a systematic or continuous basis and generally is not published. Diversions and gross applications for irrigation water are estimated by inference from such information as water licences that are held by individual irrigators. The implicit assumption is that the irrigator uses all the water to which he has a right, ragardless of its cost and regardless of the cost of application and drainage.

The technique used to undertake such studies are not without limitations. Using regression analysis precludes the inclusion of several variables (such as yield response to water application and water loses) which affect water use. The technique is applicable to specific conditions regarding the error terms and the nature of the relationships between the dependent and independent variables.

FURTHER RESEARCH NEEDS

This study focused on the development of a regression model for irrigation water use analysis. Some of the variables which could have affected water use were omitted from the model due to lack of data.

Studies are needed to determine alternative productive opportunities, both in terms of physical requirements and economic costs and returns. There are several important variables about which understanding is still quite limited. These include: farmers' responses to new technologies and production possibilities, the effect of provision of credit facilities on the farmers' willingness to invest in irrigation facilites, and the impact of different types of public policy such as direct subsidies and price support on irrigation farming. Data should be collected for such variables and should be published in the form of reports. Efforts should be made to work out some pricing system because adoption of a pricing system for irrigation water use would release water for other uses and would create more efficient use of available water.

Information regarding water losses from headgate to farm should be maintained. Data on water use efficiency would be useful in working out some measures to check losses if they are above average. Furthermore, this would help to save water which could be diverted to other areas where it is not available in the quantity needed or it could be stored to meet the conditions of drought.

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APPENDIX

APPENDIX

CONSUMPTIVE USE COMPUTATION PROCEDURE

Many factors influence the amount of water consumed by plants. The more important natural influences are climate, water supply, soil and topography. The climatic factors believed to have the greatest effect on consumptive use are temperature, precipitation, humidity, wind movement and growing season. Irrigation practices, kind of crops grown, their stage of growth and species also influence the amount of water consumed.

There are several methods available to calculate evapotranspiration, none of which are free from assumptions, arbitrary constants or technical difficulties (e.g., data measurement). The Blaney-Criddle method is based on the assumption that the consumptive use of water by a particular crop varies as:

a. the type of crop grown,
b. the temperature,
c. the length of the growing season, and
d. the monthly percentage of annual daytime hours.

This formula shows a relationship between temperature, length of growing season, monthly percentage of daytime hours and consumptive use of water. The procedure developed allows for the computation of consumptive use of each crop if the monthly temperature, latitude and growing period of the crop are known and if the computed monthly percentage of annual daytime hours are available.

Seasonal consumptive use in inches can be estimated from the formula:

$$U = KF$$

where:

U = consumptive use of water in inches;

K = empirical seasonal coefficient;

F = sum of monthly factors (f) for the season (sum of the products of mean monthly temperature (t) in degree Fahrenheit and monthly percentage of annual daytime hours (p)).

The percentage of annual daytime hours (p) for each month of the growing season for the EID are presented below:

Monthly Percentage of Annual Daytime Hours (p)

Month	p	Month	p
January	5.83	June	10.99
February	6.25	July	11.08
March	8.22	August	10.03
April	9.25	September	8.47
May	10.72		

The figures for average monthly temperature (t) are given in Table 2. The monthly factor (f) was calculated by:

$$f = \frac{t \times p}{100}$$

or

$$F = \Sigma f$$

or

$$F = \frac{\Sigma t \times p}{100}$$

The computed values for "U" for each crop are given in Tables 3 to 12. Average monthly rainfall and effective rainfall are presented in Table 2 for each year for the months of May to September.

Table 1

The Seasonal Consumptive Use Coefficient (K) for Crops in the Eastern Irrigation District

S. No.	Crop	Month				
		May	June	July	Aug.	Sept.
1	Alfalfa	0.88	1.00	0.96	0.80	0.53
2	Grass	0.70	0.98	1.10	1.02	0.50
3	Clover Hay & Seed	0.40	0.70	0.98	1.10	0.50
4	Potatoes	0.45	0.75	0.90	0.80	0.40
5	Corn	0.50	0.65	0.75	0.80	----
6	Wheat	0.45	0.78	1.05	0.40	----
7	Flax	0.55	0.70	1.00	1.10	----
8	Barley	----	0.87	1.00	0.40	----
9	Peas	----	0.50	0.90	0.98	----

Source: Harry F. Blaney and Wayne D. Criddle, Determining Consumptive Use and Irrigation Water requirements, Tachnical Bulletin No. 1275 (Washington, D.C.: U.S.D.A., 1962), pp. 49-52.

Table 2

Average Monthly Temperature (T), Average Rainfall (r) and Effective Rainfall (re) in EID From 1958-1972

Year	Temperature (T) °F					Average Rainfall (r) inches[1]					Effective Rainfall (re) inches[2]				
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
1958	57.6	58.9	63.4	66.0	53.0	0.76	1.77	1.70	0.75	1.99	0.72	1.63	1.58	0.71	1.84
1959	47.0	59.2	66.2	59.9	50.9	1.57	1.78	1.72	1.80	0.54	1.46	1.65	1.60	1.67	0.51
1960	51.1	58.9	70.8	63.1	54.2	0.75	1.56	0.64	2.41	0.11	0.71	1.45	0.61	2.19	0.10
1961	53.5	67.7	65.4	68.5	48.6	1.21	0.50	1.31	0.15	0.36	1.14	0.48	1.23	0.14	0.34
1962	51.6	62.1	62.8	63.5	53.3	1.66	1.16	1.72	0.74	1.82	1.54	1.09	1.60	0.70	1.69
1963	51.2	60.6	65.4	64.3	59.7	0.70	5.21	0.78	2.53	1.80	0.67	3.82	0.74	2.28	1.67
1964	52.7	60.2	67.1	62.0	49.2	1.84	2.09	1.74	1.13	2.16	1.70	1.92	1.62	1.06	1.98
1965	50.4	58.5	66.2	65.3	43.2	1.57	5.67	0.91	3.69	1.98	1.46	3.96	0.86	3.12	1.83
1966	54.2	57.6	64.5	61.0	57.7	0.96	3.26	4.65	2.39	0.55	0.91	2.84	3.61	2.17	0.52
1967	48.9	57.8	66.2	66.7	61.5	0.76	2.28	0.71	0.59	0.14	0.71	2.08	0.67	0.56	0.13
1968	49.5	58.6	63.7	60.2	53.9	2.75	2.43	1.37	0.62	3.01	2.47	2.20	1.28	0.59	2.67
1969	54.3	59.4	64.1	65.5	55.3	0.60	2.15	0.99	0.20	1.08	0.57	1.97	0.94	0.18	1.02
1970	53.2	65.1	67.3	65.4	51.6	0.78	5.98	0.37	0.16	1.11	0.74	4.02	0.35	0.13	1.05
1971	53.8	59.2	64.0	70.3	49.9	1.78	1.41	1.16	1.16	1.14	1.65	1.32	1.09	1.09	1.08
1972	52.9	61.8	60.5	67.1	47.1	1.46	2.25	1.59	0.52	1.73	1.36	2.06	1.47	0.49	1.61

Source: [1] Monthly Record, Meteorological Observations in Canada, Environment Canada, Ontario, 1958-1972.

[2] Calculated on the basis of the formula from Harry F. Blaney and Wayne D. Criddle, Determining Consumptive Use and Irrigation Water Requirements, Technical Bulletin No. 1275, (Washington, D.C.: USDA, 1962), p. 13.

Table 3

Computed Normal Monthly Consumptive Use and Irrigation Requirements for ALFALFA in Eastern Irrigation District

Year	Monthly Consumptive Use (U)[1]					Monthly Irrigation Requirements[2] (U-re)					
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.	Total[3]
1958	5.43	6.47	6.74	5.30	2.38	4.71	4.84	5.16	4.59	0.54	19.84
1959	4.44	6.51	7.05	4.81	2.28	2.98	4.86	5.45	3.14	1.77	18.20
1960	4.82	6.47	7.53	5.06	2.43	4.11	5.02	6.92	2.87	2.33	21.25
1961	5.05	7.44	6.96	5.50	2.18	3.91	6.96	5.73	4.36	1.84	22.80
1962	4.87	6.82	6.68	5.10	2.39	3.34	5.73	5.08	4.40	0.70	19.25
1963	4.83	6.66	6.96	5.16	2.68	4.16	2.84	6.22	2.88	1.01	17.11
1964	4.97	6.62	7.13	4.98	2.21	3.27	[illegible].70	5.51	3.92	0.23	17.63
1965	4.75	6.43	7.05	5.24	1.94	3.29	2.47	6.19	2.12	0.11	14.18
1966	5.11	6.33	6.86	4.90	2.59	4.20	3.49	3.25	2.73	2.07	15.74
1967	4.61	6.35	7.05	5.35	2.76	3.90	4.27	6.38	4.79	2.63	21.97
1968	4.67	6.44	6.78	4.83	2.42	2.20	4.24	5.50	4.24	-0.25	16.18
1969	5.12	6.53	6.82	5.26	2.48	4.55	4.56	5.88	5.08	1.46	21.53
1970	5.02	7.15	7.16	5.25	2.32	4.28	3.13	6.81	5.10	1.27	20.59
1971	5.08	6.51	6.81	5.64	2.24	3.43	5.19	5.72	4.55	1.16	20.05
1972	4.99	6.79	6.43	5.38	2.11	3.63	4.73	4.96	4.89	0.50	18.71

Mean = 19.00

[1] $U = k\Sigma \frac{t \times p}{100} = KF$.

[2] Irrigation requirement = (U-re).

[3] (U-re) from May to September.

Table 4

Computed Normal Monthly Consumptive Use and Irrigation Requirements For PASTURES in Eastern Irrigation District

Year	Monthly Consumptive Use (U)[1]					Monthly Irrigation Requirements[2] (U-re)					
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.	Total[3]
1958	4.57	5.43	6.11	5.63	3.50	3.85	3.80	4.53	4.92	1.66	18.76
1959	3.73	5.47	6.39	5.11	3.21	2.28	3.82	4.79	3.44	2.70	17.03
1960	4.06	5.43	6.82	5.38	3.58	3.35	3.98	6.21	3.19	3.46	20.19
1961	4.25	6.25	6.31	5.84	3.21	3.11	5.77	5.08	5.70	2.87	22.53
1962	4.09	5.73	6.06	5.41	3.52	2.55	4.64	4.46	4.71	1.84	18.20
1963	4.06	5.59	6.31	5.48	3.95	3.39	1.77	5.57	3.20	2.28	16.21
1964	4.18	5.56	6.46	5.29	3.25	2.48	3.64	4.84	4.23	1.27	16.46
1965	4.00	5.40	6.39	5.57	2.85	2.54	1.44	5.53	2.45	1.02	12.98
1966	4.30	5.32	6.22	5.20	3.81	3.39	2.35	2.61	3.03	3.29	14.67
1967	3.88	5.33	6.39	5.69	4.06	3.17	3.25	5.72	5.13	3.93	21.20
1968	3.93	5.41	6.14	5.13	3.56	1.51	3.21	4.86	4.54	0.89	15.01
1969	4.31	5.49	6.18	5.58	3.65	3.74	3.52	5.24	5.40	2.63	20.53
1970	4.22	6.01	6.49	5.58	3.41	3.48	1.99	6.14	5.43	2.36	19.40
1971	4.27	5.47	6.17	5.99	3.30	2.62	4.15	5.08	4.90	2.22	19.97
1972	4.20	5.70	5.83	5.72	3.11	2.84	3.64	4.36	5.23	1.50	17.57

Mean = 18.05

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[1] $U = k\Sigma\frac{t \times p}{100} = KF$.

[2] Irrigation requirement = (U-re).

[3] (U-re) from May to September.

Table 5

Computed Normal Monthly Consumptive Use and Irrigation Requirements For GRASS in Eastern Irrigation District

Year	Monthly Consumptive Use (U)[1]					Monthly Irrigation Requirements[2] (U-re)					Total[3]
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.	
1958	4.32	6.34	7.72	6.75	2.25	3.60	4.71	6.14	6.04	0.41	20.90
1959	3.53	6.38	8.07	6.13	2.16	2.08	4.73	6.47	4.46	1.65	19.39
1960	3.84	6.34	8.62	6.46	2.30	3.13	4.89	8.01	4.27	2.20	22.50
1961	4.02	7.29	7.98	7.01	2.06	2.88	6.81	6.75	6.87	1.72	25.03
1962	3.87	6.68	7.66	6.50	2.26	2.33	5.59	6.06	5.80	0.58	20.36
1963	3.84	6.53	7.98	6.58	2.53	3.17	2.71	7.24	4.30	0.86	18.28
1964	3.96	6.49	8.17	6.34	2.09	2.26	4.57	6.55	5.28	0.11	18.77
1965	3.78	6.30	8.07	6.68	1.83	2.32	2.34	7.21	3.56	----	15.43
1966	4.07	6.20	7.87	6.24	2.45	3.16	3.23	4.26	4.07	1.93	16.65
1967	3.67	6.22	8.07	6.82	2.61	2.96	4.14	7.40	6.26	2.48	23.24
1968	3.72	6.31	7.77	6.16	2.28	1.30	4.11	6.49	5.57	-0.39	17.47
1969	4.07	6.40	7.81	6.70	2.34	3.50	4.43	6.87	6.52	1.32	22.64
1970	3.99	7.01	8.21	6.69	2.19	3.25	2.99	7.86	6.54	1.14	21.78
1971	4.04	6.38	7.80	7.19	2.12	2.39	5.06	6.71	6.10	1.04	21.30
1972	3.97	6.65	7.37	6.86	1.99	2.61	4.59	5.90	6.37	0.38	19.85

Mean = 20.24

[1] $U = K\Sigma \frac{t \times p}{100} = KF$.

[2] Irrigation requirement = (U-re).

[3] (U-re) from May to September.

Table 6

Computed Normal Monthly Consumptive Use and Irrigation Requirements For CLOVER HAY and SEED in Eastern Irrigation District

Year	Monthly Consumptive Use (U)[1]					Monthly Irrigation Requirements[2] (U-re)					Total[3]
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.	
1958	2.47	4.53	6.88	7.28	2.25	1.75	2.90	5.30	6.57	0.41	16.93
1959	2.02	4.56	7.19	6.61	2.16	0.56	2.91	5.59	4.94	1.65	15.65
1960	2.19	4.53	7.68	6.96	2.30	1.48	3.08	7.07	4.77	2.20	18.60
1961	2.30	5.21	7.11	7.56	2.06	1.16	4.73	5.88	7.42	1.72	20.91
1962	2.21	4.77	6.82	7.01	2.26	0.67	3.68	5.22	6.31	0.57	16.45
1963	2.20	4.66	7.11	7.10	2.53	1.53	0.84	6.37	4.82	0.86	14.42
1964	2.26	4.63	7.28	6.84	2.09	0.56	2.71	5.66	5.78	0.11	14.82
1965	2.16	4.50	7.19	7.21	1.83	0.70	0.54	6.33	4.09	----	11.66
1966	2.32	4.43	7.01	6.73	2.45	1.41	1.59	3.40	4.56	1.93	12.89
1967	2.10	4.45	7.19	7.36	2.61	1.39	2.37	6.52	6.80	2.48	19.56
1968	2.12	4.51	6.92	6.64	2.29	0.35	2.31	5.64	6.05	0.38	14.00
1969	2.33	4.57	6.96	7.23	2.34	1.76	2.60	6.02	7.05	1.32	18.75
1970	2.28	5.01	7.31	5.02	2.19	1.54	0.99	6.96	4.87	1.14	15.50
1971	2.31	4.56	6.95	7.76	2.12	0.66	3.24	5.86	6.67	1.04	17.47
1972	2.27	4.75	6.57	7.40	1.99	0.91	2.69	5.10	6.91	0.38	15.99

Mean = 16.24

[1] $U = k\Sigma\frac{t \times p}{100} = KF$.

[2] Irrigation requirement = (U-re).

[3] (U-re) from May to September.

Table 7

Computed Normal Monthly Consumptive Use and Irrigation Requirements For POTATOES in Eastern Irrigation District

	Monthly Consumptive Use (U)[1]					Monthly Irrigation Requirements[2] (U-re)					
Year	May	June	July	Aug.	Sept. Mid.*	May	June	July	Aug.	Sept. Mid*	Total[3]
1958	2.78	4.85	6.32	5.30	0.90	2.06	3.22	4.74	4.59	-0.02	14.61
1959	2.27	4.88	6.61	4.81	0.86	0.81	3.23	5.01	3.14	0.60	12.79
1960	2.47	4.85	7.06	5.04	0.92	1.76	3.40	6.45	2.85	0.87	15.33
1961	2.58	5.58	6.53	5.50	0.82	1.44	5.10	5.30	5.36	0.65	17.85
1962	2.49	5.12	6.24	5.10	0.90	0.95	4.03	4.64	4.40	0.06	14.08
1963	2.47	5.00	6.53	5.16	1.01	1.80	1.18	5.79	2.88	0.17	11.82
1964	2.54	4.97	6.69	4.98	0.84	0.84	2.05	5.07	3.92	-0.15	12.88
1965	2.43	4.82	6.61	5.24	0.73	0.97	0.86	5.75	2.12	-0.19	9.70
1966	2.61	4.75	6.44	4.90	0.98	1.50	1.91	2.83	2.73	0.72	9.69
1967	2.36	4.76	6.61	5.34	1.04	1.65	2.68	5.94	4.79	0.97	16.03
1968	2.39	4.83	6.35	4.83	0.92	-0.08	2.63	5.07	4.24	-0.42	11.94
1969	2.62	4.90	6.39	5.26	0.94	2.05	2.93	5.45	5.08	0.43	15.94
1970	2.57	5.36	6.71	5.25	0.88	1.83	1.34	6.36	5.10	0.35	14.98
1971	2.60	4.88	6.38	5.64	0.85	0.95	3.56	5.29	4.55	0.31	14.66
1972	2.55	5.09	6.03	5.38	1.00	1.19	3.03	4.56	4.89	0.17	13.84

*First 15 days of September. Mean = 12.74

[1] $U = k\Sigma\frac{t \times p}{100} = KF$

[2] Irrigation requirement = (U-re).

[3] (U-re) from May to Mid-September.

Table 8

Computed Normal Monthly Consumptive Use and Irrigation Requirements For CORN in Eastern Irrigation District

Year	Monthly Consumptive Use (U)[1]				Monthly Irrigation Requirements[2] (U-re)				
	May	June	July	Aug.	May	June	July	Aug.	Total[3]
1958	3.08	4.21	5.27	5.30	2.36	2.58	3.69	4.59	13.22
1959	2.52	4.23	5.51	4.81	1.07	2.58	3.91	3.14	10.70
1960	2.74	4.21	5.88	5.06	2.03	2.76	5.27	2.87	12.93
1961	2.87	4.84	5.44	5.50	1.73	4.36	4.21	5.36	15.66
1962	2.77	4.33	5.22	5.10	1.23	3.24	3.62	4.40	12.49
1963	2.75	4.33	5.44	5.16	2.08	0.51	4.70	2.88	10.17
1964	2.83	4.30	5.57	4.98	1.13	2.38	3.95	3.92	11.38
1965	2.70	4.18	5.51	5.24	1.24	0.22	4.65	2.12	8.23
1966	2.91	4.11	5.36	4.90	2.00	1.14	1.75	2.73	7.62
1967	2.62	4.13	5.51	5.32	1.91	2.05	4.84	4.79	13.59
1968	2.66	4.19	5.30	4.83	0.24	1.99	4.02	4.24	10.49
1969	2.91	4.24	5.33	5.26	2.34	2.27	4.39	5.08	14.08
1970	2.85	4.65	5.60	4.45	2.11	0.63	5.25	4.30	12.29
1971	2.89	4.23	5.32	5.64	1.24	2.91	4.23	4.55	12.93
1972	2.84	4.41	5.03	5.38	1.48	2.35	3.56	4.89	12.28

Mean = 11.87

[1] $U = k\Sigma \frac{t \times p}{100} = KF$.

[2] Irrigation requirement = (U-re).

[3] (U-re) from May to August.

Table 9

Computed Normal Monthly Consumptive Use and Irrigation Requirements For WHEAT in Eastern Irrigation District

Year	Monthly Consumptive Use (U)[1]				Monthly Irrigation Requirements[2] (U-re)				
	May	June	July	Aug. Mid*	May	June	July	Aug. Mid*	Total[3]
1958	2.78	5.05	7.37	1.32	2.06	3.42	5.79	0.96	12.23
1959	2.27	5.08	7.71	1.20	0.81	3.43	6.11	0.36	10.71
1960	2.47	5.05	8.23	1.27	1.76	3.60	7.42	0.17	12.95
1961	2.58	5.80	7.61	1.38	1.44	5.32	6.38	1.31	14.45
1962	2.49	5.32	7.31	1.28	0.95	4.23	5.71	0.93	11.82
1963	2.47	5.19	7.61	1.29	1.80	1.37	6.87	0.15	10.19
1964	2.54	5.16	7.80	1.24	0.84	3.24	6.18	0.71	10.97
1965	2.43	5.02	7.71	1.31	0.97	1.06	6.85	-0.25	8.88
1966	2.61	4.94	7.51	1.22	1.50	2.10	3.90	0.13	7.63
1967	2.36	4.95	7.71	1.34	1.65	2.87	7.04	1.06	12.62
1968	2.39	5.02	7.41	1.21	-0.08	4.82	6.13	0.92	11.87
1969	2.62	5.09	7.46	1.52	2.05	3.12	6.52	1.43	13.12
1970	2.57	5.58	7.83	1.31	1.83	1.56	7.48	1.23	12.10
1971	2.60	5.08	7.44	1.41	0.95	3.77	6.35	0.86	11.93
1972	2.55	5.30	7.04	1.35	1.19	3.24	5.57	1.10	11.10

*First 15 days of August

Mean = 11.50

[1] $U = k\Sigma \frac{t \times p}{100} = KF$.

[2] Irrigation requirement = (U-re).

[3] (U-re) from May to Mid-August.

Table 10

Computed Normal Monthly Consumptive Use and Irrigation Requirements For FLAX in Eastern Irrigation District

Year	Monthly Consumptive Use (U)[1]				Monthly Irrigation Requirements[2] (U-re)				
	May	June	July	Aug. Mid*	May	June	July	Aug. Mid*	Total[3]
1958	3.39	4.53	7.02	3.64	2.67	2.90	5.44	3.28	14.29
1959	2.77	4.56	7.34	3.30	1.31	2.91	5.74	2.46	12.42
1960	3.01	4.53	7.84	3.49	2.30	3.08	7.23	2.39	15.00
1961	3.16	5.21	7.25	3.78	2.02	4.73	6.02	3.71	16.48
1962	3.04	4.77	6.96	3.51	1.50	3.68	5.36	3.16	13.70
1963	3.02	4.66	7.25	3.55	2.35	0.84	6.51	2.41	12.11
1964	3.11	4.63	7.43	3.42	1.41	2.71	5.81	2.89	12.82
1965	2.97	4.50	7.34	3.61	1.51	0.54	6.48	2.05	10.58
1966	3.20	4.43	7.15	3.37	2.29	1.59	3.54	2.28	9.70
1967	2.88	4.45	7.34	3.69	2.17	2.37	6.67	3.41	14.62
1968	2.92	4.51	7.06	3.32	0.45	2.31	6.78	3.03	12.57
1969	3.20	4.57	7.10	4.17	2.63	2.60	6.16	4.08	15.47
1970	3.14	5.01	7.46	3.61	2.40	0.99	7.11	3.53	14.03
1971	3.17	4.56	7.09	3.88	1.52	3.24	6.00	3.33	14.09
1972	3.12	4.75	6.70	3.71	1.76	2.69	5.23	3.46	13.14

*First 15 days of August.

Mean = 13.40

[1] $U = k\Sigma \frac{t \times p}{100} = KF$

[2] Irrigation requirement = (U-re).

[3] (U-re) from May to Mid-August.

Table 11

Computed Normal Monthly Consumptive Use and Irrigation Requirements For BARLEY in Eastern Irrigation District

Year	Monthly Consumptive Use (U)[1]			Monthly Irrigation Requirements[2] (U-re)			Total[3]
	June	July	Aug.	June	July	Aug.	
1958	5.63	7.02	2.65	4.00	5.44	1.94	11.38
1959	5.66	7.34	2.40	4.01	5.74	0.73	10.48
1960	5.63	7.84	2.53	4.18	7.23	0.34	11.75
1961	6.47	7.25	2.75	5.99	6.02	2.61	14.62
1962	5.93	6.96	2.55	4.84	5.36	1.80	12.00
1963	5.79	7.25	2.58	1.97	6.51	0.30	8.78
1964	5.76	7.43	2.49	3.84	5.81	1.43	11.08
1965	5.59	7.34	2.62	1.62	6.48	-0.50	8.11
1966	5.51	8.15	2.45	2.67	3.54	0.28	6.49
1967	5.52	7.34	2.68	3.44	6.67	2.12	12.23
1968	5.60	7.06	2.42	3.40	5.78	1.83	11.01
1969	5.68	7.10	2.63	3.71	6.16	2.45	12.32
1970	6.22	6.46	2.62	2.20	7.11	2.47	11.78
1971	5.66	7.09	2.82	4.34	6.00	1.73	12.07
1972	5.91	6.70	2.69	3.85	5.23	2.20	11.28

Mean = 11.03

[1] $U = k\Sigma\frac{t \times p}{100} = KF$.

[2] Irrigation requirement = (U-re).

[3] (U-re) from June to August.

Table 12

Computed Normal Monthly Consumptive Use and Irrigation Requirements For PEAS in Eastern Irrigation District

	Monthly Consumptive Use (U)[1]			Monthly Irrigation Requirements[2] (U-re)			
Year	June	July	Aug.	June	July	Aug.	Total[3]
1958	3.24	6.32	6.49	1.61	4.74	5.78	12.13
1959	3.26	6.61	5.89	1.61	5.01	4.22	10.84
1960	3.24	7.06	6.20	1.79	6.45	4.01	12.25
1961	3.72	6.53	6.73	3.24	5.30	6.59	15.13
1962	3.41	6.26	6.24	2.32	4.66	5.54	12.52
1963	3.33	6.53	6.32	-0.49	5.79	4.04	9.83
1964	3.31	6.69	6.10	1.39	5.07	5.04	11.50
1965	3.22	6.61	6.42	-0.74	5.75	3.30	9.05
1966	3.17	6.44	6.00	0.20	2.83	3.83	6.86
1967	3.18	6.61	6.56	1.10	5.94	6.00	13.04
1968	3.22	6.35	5.92	1.02	6.07	5.33	12.42
1969	3.27	6.39	6.44	1.30	5.45	6.26	13.01
1970	3.58	6.71	6.43	-0.44	6.36	6.28	12.64
1971	3.26	6.38	6.91	1.94	5.29	5.82	13.05
1972	3.40	6.03	6.60	1.34	4.56	6.11	12.01

Mean = 11.75

[1] $U = k\Sigma \frac{t \times p}{100} = KF$.

[2] Irrigation requirement = (U-re).

[3] (U-re) from June to August.

Table 13

Precipitation During the Pre-growing Season (January to April) in Inches

Year	Months January	 February	 March	 April	Total
1958	0.14	1.18	0.30	0.53	2.15
1959	0.98	0.57	0.04	0.34	1.93
1960	0.54	0.87	0.21	1.23	2.85
1961	0.19	0.93	0.28	0.42	1.82
1962	0.44	0.37	0.54	0.14	1.49
1963	1.92	0.68	0.20	0.19	2.99
1964	0.77	0.09	0.59	0.90	2.35
1965	0.36	0.43	0.71	0.64	2.14
1966	1.49	0.24	0.03	1.05	2.81
1967	0.85	0.67	0.92	3.28	5.72
1968	0.37	0.12	0.26	0.67	1.42
1969	1.13	0.57	0.35	0.69	2.74
1970	1.15	0.19	0.85	0.73	2.92
1971	1.85	0.47	0.47	0.65	3.44
1972	0.77	1.05	0.27	0.77	2.86

Source: Monthly Weather Reports, 1958-1972.

Mean = 2.64

Table 14

Area Irrigated (in Acres) and Net Consumptive Requirements (in Inches) For Different Crops in Eastern Irrigation District

Year	Water Diverted (Acre-Feet)	Area Under Wheat (Acres)	Net Consumptive Use For Wheat (Inches)	Area Under Flax (Acres)	Net Consumptive Use For Flax (Inches)	Area Under Oilseed Crops (Acres)	Net Consumptive Use For Oilseed (Inches)
				Group 1			
1958	478,700	20,587	12.23	5,133	14.29	---	-----
1959	416,300	22,739	10.71	8,219	12.42	529	12.42
1960	493,100	17,761	12.95	9,788	15.00	268	15.00
1961	652,200	16,075	14.45	8,717	16.48	177	16.48
1962	566,800	18,321	11.82	7,296	13.70	183	13.70
1963	486,100	19,144	10.10	6,611	12.11	65	12.11
1964	497,300	24,769	10.97	10,819	12.82	121	12.82
1965	349,200	23,867	8.88	13,935	10.58	7	10.58
1966	386,700	24,494	7.63	11,796	9.70	319	9.70
1967	443,900	29,186	12.62	6,673	14.62	---	-----
1968	491,400	27,968	11.87	11,804	12.57	60	12.57
1969	487,200	23,288	13.12	8,792	15.47	115	15.47
1970	398,200	10,387	12.10	9,672	14.03	270	14.03
1971	512,700	15,571	11.93	3,938	14.09	707	14.09
1972	556,840	20,454	11.10	2,053	13.14	837	13.14
Mean =	481,109	20,974	11.50	8,218	13.40	281	13.40

Table 14 (continued)

Year	Water Diverted (Acre-Feet)	Area Under Oats (Acres)	Area Under Rye (Acres)	Area Under Mixed-Grains (Acres)	Area Under Green-Feed (Acres)	Net Consumptive Use for Oats, Rye, Mixed-Grains & Green-Feed (Inches)	Area Under Barley (Acres)	Net Consumptive Use (Inches)
			Group II				Group III	
1958	478,700	22,211	356	5,550	2,813	11.38	24,037	11.38
1959	416,300	23,082	239	6,224	8,696	10.48	26,489	10.48
1960	493,100	20,513	198	4,617	7,187	11.75	19,067	11.75
1961	652,200	19,475	408	5,278	9,450	14.62	16,848	14.62
1962	566,800	23,094	373	6,510	4,928	12.00	14,868	12.00
1963	486,100	18,305	295	4,862	3,201	8.78	20,346	8.78
1964	497,300	14,989	309	5,200	3,217	11.08	20,790	11.08
1965	349,200	15,359	318	5,568	2,647	8.11	23,034	8.11
1966	386,700	16,374	250	6,512	2,496	6.49	29,943	6.49
1967	443,900	11,549	255	3,807	3,833	12.23	37,932	12.23
1968	491,400	14,398	55	5,041	2,977	11.01	41,633	11.01
1969	487,200	13,066	659	3,600	6,064	12.32	41,216	12.32
1970	398,200	13,854	314	3,547	5,717	11.78	33,488	11.78
1971	512,700	12,803	478	3,727	5,734	12.07	43,722	12.07
1972	556,840	14,605	864	4,491	6,276	11.28	37,832	11.28
Mean =	481,109	16,906	358	4,969	5,015	11.03	28,750	11.03

Table 14 (continued)

Year	Water Diverted (Acre-Feet)	Area Under Peas (Acres)	Area Under Vegetables (Acres)	Net Consump-tive Use For Peas & Vegetables (Inches)	Area Under Potatoes (Acres)	Net Consumptive Use For Potatoes (Inches)	Area Under Are Corn (Acres)	Net Consump-tive Use For Corn (Inches)
				Group IV				
1958	478,700	1,136	876	12.13	1,387	14.61	769	13.22
1959	416,300	2,218	956	10.84	1,545	12.79	479	10.70
1960	493,100	2,530	700	12.25	1,510	15.33	677	12.93
1961	652,200	3,486	453	15.13	2,005	17.85	603	15.66
1962	566,800	1,610	793	12.52	2,231	14.08	785	12.49
1963	486,100	2,136	842	9.82	2,257	11.82	1,315	10.17
1964	497,300	2,955	762	11.50	2,564	12.88	1,265	11.38
1965	349,200	2,733	544	9.05	3,020	9.70	1,031	8.23
1966	386,700	2,961	157	6.86	3,433	9.69	528	7.62
1967	443,900	3,890	1,411	13.04	2,894	16.03	495	13.59
1968	491,400	5,288	1,261	12.42	3,783	11.94	795	10.49
1969	487,200	6,289	1,702	13.01	3,726	15.94	916	14.08
1970	398,200	5,264	1,869	12.64	4,907	14.98	695	12.29
1971	512,700	3,275	2,604	13.05	5,003	14.66	1,234	12.93
1972	556,840	1,556	2,053	12.01	4,275	13.84	1,374	12.28
Mean	481,109	3,155	1,132	11.75	2,969	12.74	864	11.87

Table 14 (continued)

Year	Water Diverted (Acre-Feet)	Area Under Alfalfa Hay (Acres)	Area Under Alfalfa Seed (Acres)	Net Consumptive Use For Alflafa, Hay & Seed (Inches)	Area Under Clover Hay (Acres)	Area Under Clover Seed (Acres)	Net Consumptive Use For Clover Hay & Seed (Inches)
				Group V			
1958	478,700	40,785	1,652	19.84	1,755	496	16.93
1959	416,300	31,363	765	18.20	2,134	133	15.65
1960	493,100	39,318	738	21.25	2,310	451	18.60
1961	652,200	46,165	332	22.80	3,009	421	20.91
1962	566,800	54,922	468	19.25	2,399	94	16.45
1963	486,100	54,313	1,044	17.11	1,833	268	14.42
1964	497,300	50,680	1,530	17.63	1,996	---	14.82
1965	349,200	50,085	709	14.18	367	10	11.66
1966	386,700	46,333	825	15.74	710	32	12.89
1967	443,900	42,025	822	21.97	191	38	19.56
1968	491,400	38,274	787	16.18	147	34	14.00
1969	487,200	40,765	560	21.53	470	89	18.75
1970	398,200	48,801	2,001	20.59	385	86	15.50
1971	512,700	50,225	1,895	20.05	390	490	17.47
1972	556,840	57,559	2,814	18.71	110	115	15.99
Mean =	481,109	46,108	1,129	19.00	1,214	184	16.24

Table 14 (continued)

Year	Water Diverted (Acre-Feet)	Area Under Small Seeds (Acres)	Net Consumptive Use For Small Seeds (Inches)	Area Under Grass (Acres)	Net Consumptive Use For Grass (Inches)	Total Area Irrigated (Acres)
			Group V (continued)			
1958	478,700	2,090	20.90	---	-----	131,633
1959	416,300	1,673	19.39	---	-----	137,483
1960	493,100	1,715	22.50	---	-----	129,348
1961	652,200	503	25.03	---	-----	133,405
1962	566,800	238	20.36	---	-----	139,113
1963	486,100	819	18.28	---	-----	137,656
1964	497,300	770	18.77	---	-----	142,736
1965	349,200	1,131	15.43	---	-----	144,365
1966	386,700	1,280	16.65	---	-----	148,443
1967	443,900	3,002	23.24	1,425	23.24	149,428
1968	491,400	1,973	17.47	769	17.47	157,047
1969	487,200	509	22.64	842	22.64	152,668
1970	398,200	446	21.78	589	21.78	142,292
1971	512,700	834	21.30	513	21.30	153,143
1972	556,840	982	19.85	726	19.85	158,976
Mean =	481,109	1,198	20.24	811	21.05	143,849

Source: The Board of Trustees, Eastern Irrigation District, Brooks, Annual Report (Brooks: EID Board of Trustees, 1958-72). (Printed by the Brooks Bulletin.)